DOCUMENT RESUME

ED 292 651 SE 049 001

AUTHOR	Chiappetta, Eugene L., Ed.
TITLE	Ideas and Activities for Physical Science.
INSTITUTION	Houston Univ., Tex. Coll. of Education.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	87
GRANT	DPE-8470550
NOTE	404p.; Some drawings may not reproduce well.
AVAILABLE FROM	Dr. Eugene L. Chiappetta, Dept. of Curriculum & Instruction, College of Education, University of Houston, 4800 Calhoun, Houston, TX 77004 ($15.00 plus $1.50 shipping and handling).
PUB TYPE	Guides - Classroom Use - Materials (For Learner) (051) -- Guides - Classroom Use - Guides (For Teachers) (052)
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	Chemistry; Junior High Schools; Middle Schools; *Physical Sciences; Physics; *Science Activities; *Science Curriculum; Science Education; *Science Instruction; Secondary Education; *Secondary School Science; Student Attitudes; Surveys; *Teaching Methods

ABSTRACT

This manual is designed to supplement an existing physical science curriculum and to assist in providing the learning experiences required to implement an effective course. The first chapter outlines the purposes of this manual and provides a set of teaching tips. Topics such as electricity, wave motion, light, sound, periodic table and nuclear chemistry have been treated in some detail whereas more familiar topics which are addressed in texts have received less emphasis. Each unit contains background information, paper-and-pencil exercises, demonstrations, and laboratory activities. Units include: "Turning Students on to Chemistry"; "Structure of Matter"; "The Periodic Table"; "Chemical Compounds and Equations"; "Acids and Bases"; "Nuclear Chemistry"; "Safety in the Laboratory"; "Electricity"; "Motion"; "Newton's Laws of Motion"; "Friction"; "Waves and Light"; and "Sound and Music." Also included is a questionnaire for assessment of a science course by students. (CW)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

IDEAS AND ACTIVITIES FOR PHYSICAL SCIENCE

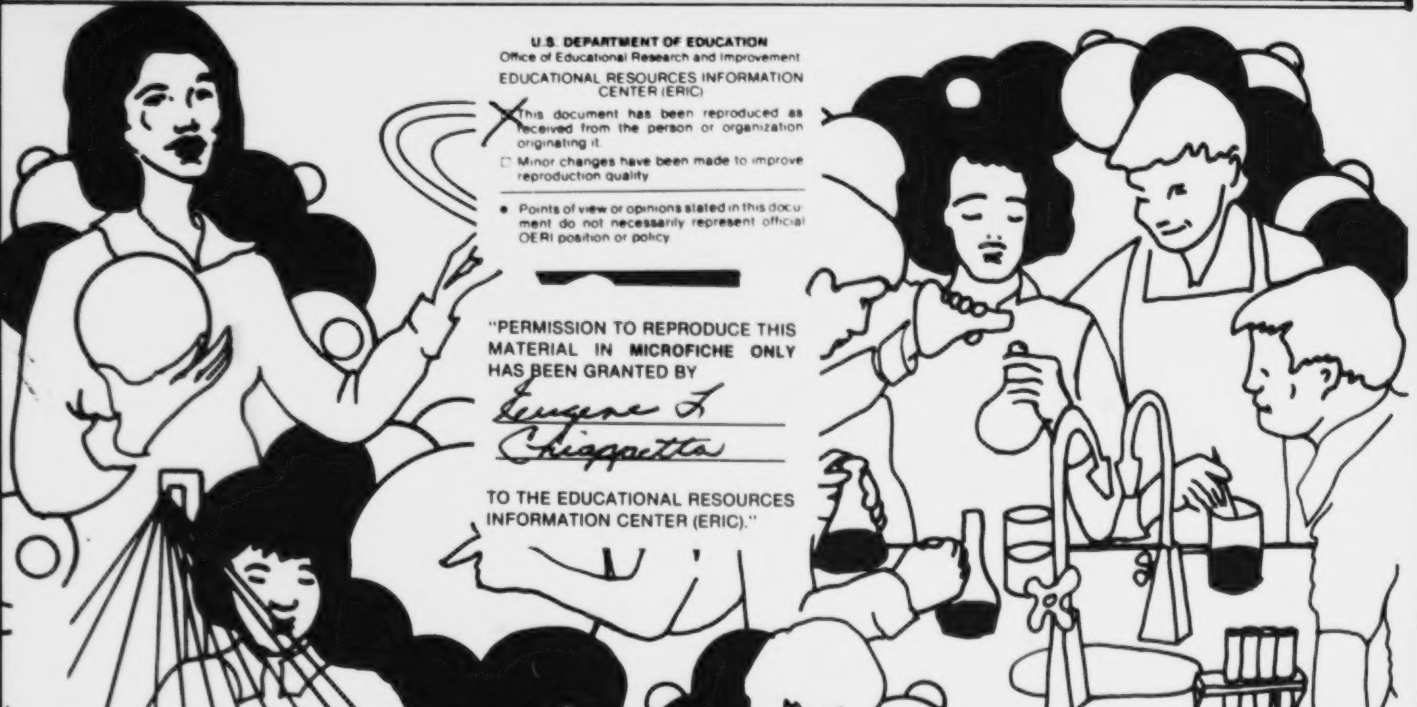
U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☒ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

● Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY
Eugene L. Chiappetta
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."



ED292651
SE 049 001

FUNDED BY A GRANT FROM THE NATIONAL SCIENCE FOUNDATION
PROJECT DIRECTOR. EUGENE L. CHIAPPETTA

BEST COPY AVAILABLE

IDEAS AND ACTIVITIES
FOR
PHYSICAL SCIENCE

Eugene L. Chiappetta, Editor
University of Houston

Published by: College of Education, University of Houston
Houston, Texas 77004

Copyright © 1987

The information, findings, and opinions expressed herein **do not** necessarily reflect the position or policy of the **National Science Foundation**.

ACKNOWLEDGEMENT

The develoment of these instructional materials was made possible by a grant from the Teacher Preparation Program Section of the Directorate for Science and Engineering Education, of the **National Science Foundation** (Grant No. DPE-8470550). The instructional materials component of the project consists of this physical science demonstration/laboratory manual and videotaped sessions which focus on the effective utilization of demonstrations and laboratory experiences for students. The information, findings, and opinions expressed herein **do not** necessarily reflect the position or policy of the **National Science Foundation**.

Grants for energy education programs in area schools and programs for the improvement of physical science instruction in the Houston ISD by **Shell Oil Company** have in large measure provided the impetus for this project. These grants have helped to focus the resources of business, industry, and the educational community on the improvement of science instruction, and they have provided the means for developing a communication network among groups.

Support has been provided by the **Houston Lighting and Power Company** through the sponsorship of courses, institutes, and field trips. These special projects have enabled teachers to learn new information and to share experiences with their colleagues.

Cooperative projects such as these focus multiple resources on specific student and teacher needs, and generate the kind of enthusiasm which is necessary for the improvement of educational programs. On behalf of the educational community, we express our appreciation to the National Science Foundation, Shell Oil Company, and Houston Lighting and Power Company for the generous and continued support of science education.

In addition, we would like to acknowledge the valuable contributions of the following people:

Marcile Hollingsworth, former Director of Science in the Houston Independent School District, for identifying a need for a physical science manual which explains selected concepts and principles, and provides laboratory activities for use by teachers.

Russell Geanangel, Professor of Chemistry at the University of Houston, for getting us started on the Apple Macintosh computer system for the production of this manual and for his assistance in helping us solve problems that arose when using this new technology.

Godrej Sethna, Project Manager, for using the desktop publishing capabilities of the Apple Macintosh computer system to produce this manual. Only through his continuous hard work did the production of the manual become a reality.

James Hutchison, Counseling Coordinator, Diagnostic Learning Center, University of Houston, for his proofreading and excellent suggestions on how to make the text clearer. He also assisted in the data collection.

Mary Sinclair, Physical Science Teacher, Katy Independent School District, Katy, Texas. She permitted us to videotape her presenting demonstrations and laboratory exercises in a live classroom.

PREFACE

This manual is designed to supplement an existing physical science curriculum and to assist in providing the learning experiences required to implement an effective course. It includes teaching tips, background information on science subject matter, and instructional activities that can be used to gain and maintain student interest during the study of a variety of physical science topics. Topics such as electricity, wave motion, light, sound, periodic table, and nuclear chemistry have been treated in some detail. More familiar topics such as friction, and acid and base chemistry, which are addressed in most current physical science texts and reference materials, have received somewhat less emphasis.

The first chapter in this manual outlines its purpose and provides a set of teaching tips. This introduction should be studied and followed by anyone who wishes to use the manual. Instructional activities, which follow in subsequent chapters, have been designed to accomplish the major objectives of this physical science improvement project: namely to raise students' interest and achievement. Any science teacher who is committed to improving what students learn about physical science can benefit by using the questioning techniques and instructional strategies detailed in the manual.

Each unit begins with background information, which serves as a review for the teacher on the key concepts and major ideas addressed in that unit. In some instances, such as in the electricity and nuclear chemistry units, information that may be new to physical science teachers is given to build their conceptual background. The paper and pencil exercises may be used to reinforce facts and concepts, while the demonstrations are designed to gain student interest and to stimulate curiosity as well as to illustrate physical science concepts and principles. The teacher's version of the laboratory exercises is thoroughly prepared and includes prelaboratory and postlaboratory discussions. It indicates where to obtain some of the materials and equipment necessary to conduct the laboratories, and also contains answers to the questions. Careful implementation of these instructional activities can produce an exciting and productive learning environment.

AUTHORS AND CONTRIBUTORS

THOMAS M. ANTHONY, Teacher, Klein Independent School District, Texas.

EUGENE L. CHIAPPETTA, Professor of Education, University of Houston. Project director, editor-in-chief, narrator for the video tapes, and author of the units: Purpose for this Manual, and Sound and Music.

CAROLYN DESSENS, Research Assistant, Department of Curriculum and Instruction, University of Houston. Illustrator for diagrams and pictures that appear in the manual.

BARBARA DUNN, Physical Science Teacher, Houston Independent School District, Texas. Author of the unit: Chemical Compounds and Equations.

BRENT FISHER, Physical Science and Physics Teacher, Cypress Fairbanks Independent School District, Texas. Author of the units: Motion, Newton's Laws of Motion, and Friction.

RUSSELL A. GEANANGEL, Professor of Chemistry, University of Houston. Author of the units: Structure of Matter and The Periodic Table, and reviewer of the chemistry units for content accuracy.

HUGH T. HUDSON, Professor of Physics, University of Houston. Reviewer of the physics units for content accuracy and author of the background information for the unit on electricity.

JAMES HUTCHISON, Counseling Coordinator, Diagnostic Learning Center, University of Houston. Proofreader of the materials in this manual.

BARBARA K. FOOTS, Assistant Director of Science, Houston Independent School District, Texas. Author of the unit: Safety in the Laboratory.

REGINA KAPTA, Graphics Specialist for the Learning Resource Center, College of Education, University of Houston. Designed the cover for this manual and the videotape guide.

GODREJ H. SETHNA, Instructor, College of Education, University of Houston. Typed the text, formatted it, and printed it on the Apple LaserWriter.

MARY SINCLAIR, Physical Science Teacher, Katy Independent School District, Texas. The teacher who demonstrated effective physical science demonstrations and laboratory procedures, which are presented on videotape.

OTIS J. SMITH, Science Coordinator for Deer Park Independent School District, Texas. Author of the unit: Waves and Light.

JAMES R. SUMPTER, Nuclear Engineer, Manager of Nuclear Services for Houston Lighting and Power Company. Author of the unit: Nuclear Chemistry.

EDNA THOMPSON, Physical Science Teacher, Houston Independent School District, Texas. Author of the units: Electricity, and Acids and Bases.

HERSHOLT C. WAXMAN, Assistant Professor of Education, University of Houston, served as a research specialist and statistician for the project.

PHYSICAL SCIENCE TEACHERS

The physical science teachers listed below participated in the research aspect of this project. They collected data on the effectiveness of the ideas and activities from the manual that were implemented into their courses. In part, it is through the efforts of these professionals that we can make specific recommendations to other science teachers on how to improve physical science. They all teach in school districts in and around Houston, Texas.

Thomas M. Anthony, Klein Oaks High School, Klein ISD

Grace Blasingame, Pasadena ISD

Jim Brevard, Klein Oaks High School, Klein ISD

Maragaret Brown, Cypress Creek High School, Cypress Fairbanks ISD

Saundra Coffey, Cypress Creek High School, Cypress Fairbanks ISD

Daniel Connolly, Lamar High School, Houston ISD

Jim Dwight, Contemporary Learning Center, Houston ISD

Margaret B. Flanagan, New Caney High School, New Caney ISD

Charles Funk, Aldine High School, Aldine ISD

Sue Gardner, Klein Oaks High School, Klein ISD

Mary Ann Geary, Willowridge High School, Fort Bend ISD

Sargent Gerstle, South Houston High School, Pasadena ISD

Wendy Giovanella, Worthing High School, Houston ISD

Huntyce E. Moore, Katy High School, Katy ISD

Brenda Owen, Katy High School, Katy ISD

Paula Robinson, Needville High School, Needville ISD

Mary Sinclair, Mayde Creek High School, Katy ISD

John Taylor, Jones High School, Houston ISD

Cindy Templeton, Austin High School, Houston ISD

Kitty Wilson, South Houston High School, Pasadena ISD

CONTENTS

Acknowledgement i

Preface ii

Authors and Contributors iii

Physical Science Teachers iv

1 Purpose of this manual Eugene Chiappetta

Introduction 1-1
Teaching Tips 1-5
  Presenting Demonstrations 1-6
  Conducting Laboratory Exercises 1-6
  Paper and Pencil Exercises 1-9
  Questioning 1-9
  Target Students 1-11
Results From the Classroom 1-11

2 Turning Students on to Chemistry Thomas Anthony

Background Information 2-1
Ingredients.......Paper & Pencil Exercise (student) 2-2
A Checklist of Food Additives... Paper & Pencil Exercise (student) 2-3
Eat Your Cereal. It's Good For You! ....Demonstration 2-6
An Apple A Day ....Demonstration 2-7
Rubber Bones........Demonstration 2-8
Investigating Proteolytic Enzymes........Laboratory Exercise (teacher) 2-9
Investigating Proteolytic Enzymes........Laboratory Exercise (student) 2-12
The Chemistry of Bruised Fruit.......Laboratory Exercise (teacher) 2-14
The Chemistry of Bruised Fruit.......Laboratory Exercise (student) 2-16
Chemistry: Sunny-Side Up.......Laboratory Exercise (teacher) 2-18
Chemistry: Sunny-Side Up.......Laboratory Exercise (student) 2-20

3 Structure of Matter Russell Geanangel

Background Information 3-1
Macroscopic Matter......Paper & Pencil Exercise (teacher) 3-7
Macroscopic Matter......Paper & Pencil Exercise (student) 3-8
Solutions and Mixtures......Laboratory Exercise (teacher) 3-9
Solutions and Mixtures......Laboratory Exercise (student) 3-13

4 *The Periodic Table* Russell Geanangel

Background Information 4-1
The Periodic Table and Formulas.....Paper & Pencil Exercise (teacher) 4-13
The Periodic Table and Formulas.....Paper & Pencil Exercise (student) 4-15
Periodic Trends in the Properties of the Elements..... Paper & Pencil Exercise (teacher) 4-17
Periodic Trends in the Properties of the Elements..... Paper & Pencil Exercise (student) 4-20
The Periodic Table......Laboratory Exercise (teacher) 4-23
The Periodic Table......Laboratory Exercise (student) 4-31

5 *Chemical Compounds and Equations* Barbara Dunn

Background Information 5-1
A Picture is Worth a Thousand Words.......A Student Project 5-3
Naming Chemical Compounds.......Paper & Pencil Exercise (teacher) 5-4
Naming Chemical Compounds.......Paper & Pencil Exercise (student) 5-5
Writing Formulas....... Paper & Pencil Exercise (teacher) 5-6
Writing Formulas....... Paper & Pencil Exercise (student) 5-7
Balancing Chemical Equations....... Paper & Pencil Exercise (teacher) 5-8
Balancing Chemical Equations....... Paper & Pencil Exercise (student) 5-9
Chemical Equations - Synthesis....... Paper & Pencil Exercise (teacher) 5-10
Chemical Equations - Synthesis....... Paper & Pencil Exercise (student) 5-11
Chemical Equations - Analysis....... Paper & Pencil Exercise (teacher) 5-12
Chemical Equations - Analysis....... Paper & Pencil Exercise (student) 5-13
Chemical Equations - Single Replacement....... Paper & Pencil Exercise (teacher) 5-14
Chemical Equations - Single Replacement....... Paper & Pencil Exercise (student) 5-15
Chemical Equations - Double Replacement....... Paper & Pencil Exercise (teacher) 5-16
Chemical Equations - Double Replacement....... Paper & Pencil Exercise (student) 5-17
Completing and Balancing Chemical Equations...Paper & Pencil Exercise (teacher) 5-18
Completing and Balancing Chemical Equations...Paper & Pencil Exercise (student) 5-19
Dancing Snowballs.......Demonstaration 5-20
Self-Propelled Sodium.......Demonstration 5-21
Aluminum To Copper? ....Demonstration 5-22
Types of Chemical Reactions.......Laboratory Exercise (teacher) 5-23
Types of Chemical Reactions.......Laboratory Exercise (student) 5-25
Do I See Spots?....... Laboratory Exercise (teacher) 5-27
Do I See Spots?....... Laboratory Exercise (student) 5-30
Determining Empirical Formulas....... Laboratory Exercise (teacher) 5-32
Determining Empirical Formulas....... Laboratory Exercise (student) 5-34

6 *Acids And Bases* Edna Thompson

Background Information 6-1
Acids and Bases.......Paper & Pencil Exercise (teacher) 6-6
Acids and Bases.......Paper & Pencil Exercise (student) 6-8
Carbon in Sugar?.......Demonstration 6-10
Magic or Chemistry?.......Demonstration 6-11
What is an Acid?......Laboratory Exercise (teacher) 6-13
What is an Acid?......Laboratory Exercise (student) 6-18
What is a Base?.......Laboratory Exercise (teacher) 6-22
What is a Base?.......Laboratory Exercise (student) 6-27
Colors Will Tell.......Laboratory Exercise (teacher) 6-30
Colors Will Tell.......Laboratory Exercise (student) 6-35

7 *Nuclear Chemistry* James Sumpter

Background Information 7-1
Decay Chain of Uranium-238......Paper & Pencil Exercise (teacher) 7-15
Decay Chain of Uranium-238......Paper & Pencil Exercise (student) 7-19
Compute Your Own Radiation Dose.....Paper & Pencil Exercise (teacher) 7-22
Compute Your Own Radiation Dose.....Paper & Pencil Exercise (student) 7-23
Public Opinion Poll On Risk......Paper & Pencil Exercise (student) 7-24
Chain Reaction......Demonstration 7-28
Observing Radioactivity with a Cloud Chamber......Demonstration 7-30
Radioactive Half-Life......Laboratory Exercise (teacher) 7-32
Radioactive Half-Life......Laboratory Exercise (student) 7-36

8 *Safety in the Laboratory* Barbara Foots

Background Information 8-1
Science Laboratory Facilities and Safety Equipment 8-2
Safety Guide for Students 8-5
Chemical Storage and Usage 8-7
Field Experiences 8-10
Student Safety Contract 8-14
Laboratory Safety Management Test.....Paper & Pencil Exercise (teacher) 8-16
Laboratory Safety Management Test.....Paper & Pencil Exercise (student) 8-17

9 *Electricity* Edna Thompson

Background Information (Tom Hudson) 9-1
Series Circuits......Paper & Pencil Exercise (teacher) 9-9
Series Circuits......Paper & Pencil Exercise (student) 9-11
Parallel Circuits......Paper & Pencil Exercise (teacher) 9-13
Parallel Circuits......Paper & Pencil Exercise (student) 9-15
Think Time......Paper & Pencil Exercise (teacher) 9-17
Think Time......Paper & Pencil Exercise (student) 9-19
Dancing Rice.......Demonstration 9-21

The Electroscope.......Demonstration 9-23
Will a Magnet Attract Aluminum?.......Demonstration 9-25
How Do Series and Parallel Circuits Work.....Laboratory Exercise (teacher) 9-26
How Do Series and Parallel Circuits Work.....Laboratory Exercise (student) 9-30
Electric Circuits......Laboratory Exercise (teacher) 9-32
Electric Circuits......Laboratory Exercise (student) 9-37
Sticky Electricity.......Laboratory Exercise (teacher) 9-41
Sticky Electricity.......Laboratory Exercise (student) 9-46

10 ***Motion*** Brent Fisher

Background Information 10-1
Motion Across the United States......Paper & Pencil Exercise (teacher) 10-8
Motion Across the United States......Paper & Pencil Exercise (student) 10-10
Motion from Here to Eternity........Demonstration 10-12
Free Fall and the Dollar Bill........Demonstration 10-13
Terminal Velocity: The Final Approach.......Demonstration 10-17
Mouse Trap Car.......Laboratory Exercise (teacher) 10-19
Mouse Trap Car.......Laboratory Exercise (student) 10-23
Rates of Change and the Mouse Trap Car.....Laboratory Exercise (teacher) 10-25
Rates of Change and the Mouse Trap Car.....Laboratory Exercise (student) 10-28

11 ***Newton's Laws of Motion*** Brent Fisher

Background Information 11-1
Practicing Using Newton's Laws.......Paper & Pencil Exercise (teacher) 11-3
Practicing Using Newton's Laws.......Paper & Pencil Exercise (student) 11-4
Newton's First Law.......Many Demostrations 11-5
Studying Newton's Laws of Motion......Laboratory Exercise (teacher) 11-10
Studying Newton's Laws of Motion......Laboratory Exercise (student) 11-13

12 ***Friction*** Brent Fisher

Background Information 12-1
Investigating Frictional Forces......Laboratory Exercise (teacher) 12-3
Investigating Frictional Forces......Laboratory Exercise (student) 12-6

13 ***Waves And Light*** Otis Smith

Background Information 13-1
Mechanical Waves.......Demonstration 13-3
Water Waves........Demonstration 13-10
Mechanical Waves (Bell Clapper Method).......Laboratory Exercise (teacher) 13-14

Mechanical Waves (Bell Clapper Method).......Laboratory Exercise (student) 13-18
Interference Patterns in Light (Thin Slits Method)..... Laboratory Exercise (teacher) 13-20
Interference Patterns in Light (Thin Slits Method)..... Laboratory Exercise (student) 13-23
Determining the Wavelength of Light (Diffraction Grating Method)....... Laboratory Exercise (teacher) 13-26
Determining the Wavelength of Light (Diffraction Grating Method)....... Laboratory Exercise (student) 13-29
Reflection from Plane Surfaces......Laboratory Exercise (teacher) 13-33
Reflection from Plane Surfaces......Laboratory Exercise (student) 13-36
Color......Laboratory Exercise (teacher) 13-38
Color......Laboratory Exercise (student) 13-42

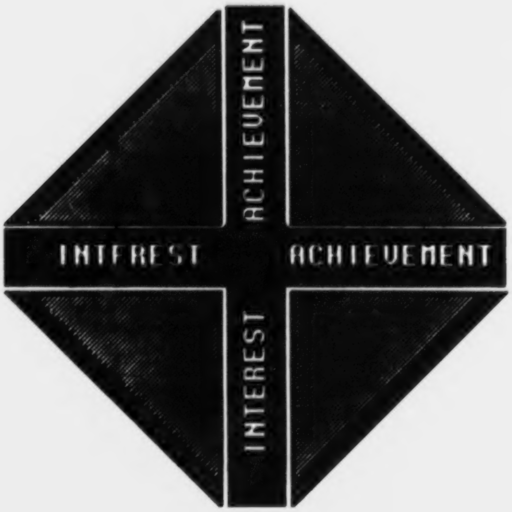
14 Sound And Music Eugene Chiappetta

Background Information 14-1
And Now....The High Lows.....Paper & Pencil Exercise (teacher) 14-9
And Now....The High Lows.....Paper & Pencil Exercise (student) 14-10
Turn It Down, I Can't Hear.....Paper & Pencil Exercise (teacher) 14-11
Turn It Down, I Can't Hear.....Paper & Pencil Exercise (student) 14-12
Sound Vibration.......Demonstration 14-13
Amplifying Sound........Demonstration 14-15
Sound and Music Through Resonance.......Demonstration 14-17
The Doppler Principle.......Demonstration 14-19
The String Telephone........Laboratory Exercise (teacher) 14-21
The String Telephone........Laboratory Exercise (student) 14-25
Play Me a Tune.......Laboratory Exercise (teacher) 14-27
Play Me a Tune.......Laboratory Exercise (student) 14-30

APPENDIX A: Questionnaire for Assessment of Science Course

Purpose of This Manual

1



This manual makes available to physical science teachers some of the best ideas and teaching tips currently used by science educators. Experienced teachers and those who have received outstanding science teaching awards, at the local and national levels, have contributed their wisdom and expertise. Each unit of the manual was authored by a specialist in that subject area or one who has experienced success in using the activities in the classroom.

A unique aspect of the manual is its synthesis of subject matter content, suggestions for experiments and demonstrations, questions for students, and tips on teaching. It is designed to be a guide to teaching physical science and a supplement to an existing course. Funded in part by a grant from the National Science Foundation and developed by faculty in the College of Education at the University of Houston, the manual draws upon current research findings on effective teaching methods. For the committed classroom teacher, here is a state-of-the-art compendium on how to instruct effectively at the middle school or high school level in the area of physical science. The manual offers a valuable supplement, and at times a revealing alternative, to existing instructional guides. Most important, dramatic results can be achieved as reported at the end of this section.

The diagram shown above captures the two primary objectives for this project. Our goal is to get students interested in science and to cause them to learn the subject matter well. These two outcomes are essential to the success of a good science course. If you get students excited about science, you can motivate them to study and to participate in a thorough plan of instruction. We have developed this manual with these ideas in mind. Every aspect of this teaching aid was constructed so that students will leave your course saying:

"I enjoyed this science class and I learned a lot."

Shoot straight for these two results. Think of your science course as a scientific experiment. The dependent variables are what students feel and learn as a result of your instruction. Specifically, the **dependent variables** are:

(1) Students' **perceptions** of their science class.
- How interesting is this class.
- How comfortable do they feel in this science class.
- How useful is the information taught in this class.

(2) Students' **achievement** of the subject matter.
- How well they scored on your tests.

Educators have long been concerned about student attitude and achievement in the physical sciences. It is well known that teenagers are less interested in chemistry and physics, than, say, biology. This interest in the physical sciences declines sharply after elementary school. The National Assessment of Educational Progress (NAEP), which is administered approximately every four years to 9, 13, and 17 year old students, has documented that achievement in physical science has declined over the past decade, whereas achievement in biology has not declined. Why are our nation's youth doing so poorly in learning the most basic concepts of chemistry and physics?

We maintain that there are at least two major reasons for this decline. The first reason is that the concepts and principles of chemistry and physics are rather abstract. This subject matter is perceived to be difficult to comprehend, and irrelevant to many students. The second reason is that the majority of people teaching physical science were not specifically trained to teach this subject. These teachers frequently have a modest preparation in chemistry and physics; they usually majored in biology. Often they are assigned to teach physical science, but not by choice. Because of their lack of background in the physical sciences, they often request and need more training in these areas.

Because of these reasons and many others, we have placed emphasis on achievement and perceptions in this manual. When science educators (Hueftle, Rakow, & Welch, 1983) analyzed the 1981-82 data from the National Assessment in Science, they found a significant correlation between what students thought of their science classes and how well they scored on science achievement tests. Therefore, we are stressing, as one of our major goals, to influence students' perceptions about their physical science course. Students should complete your science course with many positive feelings and beliefs. Below are some items from the National Assessment in Science you can use to determine students' perceptions of their science course:

HOW MUCH DO YOU ENJOY THIS SCIENCE COURSE?

a. Science class is often boring.
b. Science class is usually fun.
c I enjoyed going to science class.
d. I am afraid to ask questions.

HOW USEFUL IS THE INFORMATION TAUGHT IN THIS COURSE?

a. The information is useful to me.
b. The information is meaningful to my life.
c. This information should be required in science classes.
d. I will be able to use the information in the future.

HOW DID YOU FEEL IN SCIENCE CLASS DURING THIS COURSE?

a. I felt uncomfortable during this course.
b. I was curious.
c. The classes made me feel stupid.
d. I felt confident.
e. The class made me feel successful.
f. I was unhappy in class because of this course.

The questionnaire presented in Appendix A can be used to assess what students believe takes place in their science class and how they feel about the course. It was used in this project for these purposes and we believe the feedback you receive on these forms is very useful. We recommend that all science teachers use this type of questionnaire several times during the school year.

Again, it cannot be emphasized too strongly that you must make students feel good about their physical science class and its subject matter. Students must look forward to attending class because it is challenging and teaches them information they believe is useful. In addition, they must feel comfortable attending the class. Students must feel free to ask questions and speculate on answers to problems without the threat of criticism, which might cause them to feel foolish and embarrassed.

Along with improving students' perceptions of their physical science class, you must improve their achievement. The achievement level of the class must be relatively high. Let's be specific here and state that the class average should be over 75. We maintain that this is a reasonable level of achievement for most teaching situations. Unfortunately, this is not the case in a large proportion of the physical science classes. It is not uncommon for us to hear physical science teachers reveal class averages in the 60's. Results of this nature are an indictment against science teachers who are responsible for these classes. It is also a black mark against science courses, which cause students to say, "I cannot wait until I have completed my science requirements so that I do not have to take another science course."

The acquisition of knowledge and information useful to the lives of students is central to education. Fortunately, physical science contains a great deal of this useful information, which is essential to explanations of many phenomena in our everyday environment. Certainly, knowledge of related concepts, principles, and laws is not too much to ask adolescents to master. Mastery of basic concepts related to atoms, molecules, solutions, motion, electricity, and light, for example, can be accomplished by most teenagers.

With these outcomes or dependent variables in mind, what are the manipulative or independent variables that are stressed in this manual? Obviously, these variables are what you do in the classroom--use teaching skills and implement instructional strategies. What you do during instruction and how well you do it is critical to the results you get in your physical science course. Therefore, most of this manual is devoted to what you teach and how well you teach it. The **independent variables** are:

(1) The **frequency** of strategies used during instruction such as:
- The number of demonstrations presented.
- The number of laboratory exercises conducted.
- The number of paper and pencil exercises used.

(2) The **effectiveness** in which the strategies are implemented. The following teaching skills are important:
- The use of lower- and higher-order questions to stimulate discussion.
- The use of wait time to permit thinking and understanding.
- Calling on many students in the class to respond.
- The use of thorough pre- and post-laboratory discussions.

How can this manual help you to teach an effective science course? First, the manual provides background information, paper and pencil exercises, demonstrations, and laboratory exercises. These components will improve your knowledge of the most fundamental facts and concepts of physical science as well as to help you present concrete experiences to students. Concrete and manipulative experiences have been found to be related to improved achievement in science (Wise & Okey, 1983), and are recommended by many educators who have studied and supervised the instruction of learners who are at the concrete operational stage of development. It is important that we center the instruction of chemistry and physics concepts on events that students can see and touch. When we do this, we provide students with situations they can understand by attaching symbols to them. Once we have given students a physical situation, we can then help them to abstract the essential elements of this learning situation through verbalization.

In order to facilitate information processing, questions are used extensively throughout the manual. A variety of questions are written for teachers to ask. These questions stimulate thinking and cause students to respond. They help promote internalization of information. Questions that require students to give factual information are provided as well as questions that require students to apply information to solve problems and explain events. Although the answers to the questions are provided, we recommend you hold off on giving the answers and encourage students to come up with some of the answers on their own.

One technique that has been reported to be very effective in improving the quality of students' responses to questions is called **wait time** (Wise & Okey, 1983; Tobin & Capie, 1984). Wait time is the amount of time the teacher pauses between the time the question is asked and the student is called upon to respond. Classroom observations show that most teachers use a rapid fire approach to questioning during the instruction. These teachers ask a question and immediately call upon a student to answer, waiting only **one** second to call on a person. This leaves little time for students to think and respond in coherent ways. When teachers pause at least **three, four, and preferably five seconds** before calling on a student to respond to a question, the quality of responses improves and the achievement level of the class increases.

The mechanism by which a thorough plan of instruction produces improved achievement and attitude is well documented (Roadrangka & Yeany, 1985). Quality instruction engages students in learning tasks more than poor instruction. It causes:

- students to think,
- students to manipulate objects,
- students to explain ideas,
- students to ask questions,
- students to discuss, and
- students to write down their thoughts on paper.

This is accomplished by teachers who are rather indirect in their teaching. Indirect teachers ask more questions than direct teachers. They spend more time in class permitting students to talk and explain, than they do lecturing and giving information. Indirect teachers spend more time guiding and channeling student thinking and activity. They refrain from telling students everything. They put students on center stage and in the limelight, resulting in more "time on task" for the learner. They frequently present demonstrations which are accompanied by effective questioning sessions. When skilled teachers ask a variety of questions and allow students to think and respond, students learn to discuss in a thoughtful manner. This same type of dialogue takes place during prelaboratory and postlaboratory discussions, which makes laboratory work more meaningful. Effective teachers also employ this **highly interactive** mode of instruction during lectures/discussion, where all students are called upon, not just a select few of the most capable ones.

Frequent reviews of major concepts are encouraged: consequently, we provide paper and pencil exercises for each topic. Successful physical science teachers require their students to express their knowledge in writing. This practice reinforces learning and identifies areas that need more study.

In summary, this is an annotated demonstration/laboratory manual that will help you to be a more effective physical science teacher. It is meant to increase the frequency with which you present demonstrations and laboratories, in order that you provide concrete learning experiences for the students. The manual also provides you with information, paper and pencil exercises, and questions to stimulate thinking. These activities will cause students to process information and explain basic concepts. When students become knowledgeable about the physical world they live in, through expertly conducted science courses, they will enjoy physical science and learn this subject well.

TEACHING TIPS

If you ask teenagers or young adults what they remember about their science classes, the chances are they will recall a demonstration or a laboratory exercise which generated a great deal of excitement or interest. Most people have some positive recollections about science course experiences. These recollections rarely center around lectures, but center around concrete experiences, interesting and meaningful, which caused students to find out something for themselves.

Those of us who teach science actually have an advantage over those who teach other courses such as English, mathematics, and social studies. We have numerous demonstrations and laboratory exercises from which to draw that are of high interest to youngsters. And if we use these instructional strategies often and well, students will enjoy our courses and appreciate science.

There are good reasons why youngsters find science demonstrations and laboratory exercises interesting. Most teenagers enrolled in middle and junior high science courses are at the concrete stage of intellectual development. Concrete operational thinkers benefit from seeing an event and then forming abstractions, symbols, and models to represent the ideas mentally. This linkage between what takes place in front of students, what they do in the laboratory, and what they construct in their minds is necessary to learning physical science principles.

Much of the subject matter taught in chemistry and physics is very abstract. Consequently, we must create concrete experiences to help youngsters assimilate and accommodate these concepts. Demonstrations and laboratory exercises are ideal for providing real experiences that teenagers can see, interact with, and relate to intellectually.

In addition to the cognitive match between concrete experiences and thinking skills of teenagers, there is a social match that must be considered. Teenagers are very peer group oriented. They are interested in what their friends are doing and how they are perceived by others. Classroom activities can be structured so that participation in academic tasks is socially acceptable, ego enhancing, and scholastically productive.

This teaching aid presents demonstrations and laboratory activities that promote student involvement, while encouraging them to explain concepts and laws so that they will be successful in science courses. It also contains background information and explanations to help you understand many basic science concepts, ask good questions, stimulate lively discussions, and increase student participation.

PRESENTING DEMONSTRATIONS

Frequent use of **demonstrations** can greatly improve a physical science course. Demonstrations can make a physical science course interesting and students more knowledgeable about basic concepts. Perhaps there is nothing like a good demonstration to gain teenagers' attention and get them to speculate about the cause of an event. This manual provides numerous demonstrations -- how to prepare for them, present them, and get students to explain them.

The advantages of science demonstrations are many. Demonstrations can be used to guide thinking because you can focus attention on a concrete event and ask questions which center on key concepts. Demonstrations can permit economy of resources and allow you to use equipment and materials that would not be plentiful enough for students to use in the laboratory. With this instructional strategy, you can call on certain students to participate who might otherwise sit back in science class and do very little. Demonstrations permit you to economize on your effort and time when it comes to teaching certain principles and laws, since demonstrations are usually short, yet very instructive.

Demonstrations make special demands, which you should try to satisfy:

1. **Visibility.** Be sure that all of the students can see your demonstrations, especially the apparatus you are using. If you are using small equipment or if students sitting in the back of the class cannot see, assemble the class near the demonstration table so they can observe what is taking place. Another way to ensure that all students can see and understand the demonstration is to walk around to class members with the equipment or products of the demonstration so they can have a close-up view of this activity.

2. **Familiarity with apparatus.** Explain the apparatus and equipment you are using. This is essential for maintaining student interest in demonstrations and promoting understanding of what is taking place. Call certain students to the demonstration table to repeat or carry out a demonstration so they will learn about science equipment and how to use it.

3. **Understanding**. There is not a better opportunity to develop understanding of science principles or laws than through demonstrations. This understanding is accomplished through question-and-answer sessions which accompany demonstrations. Convergent, divergent, and probing questions are used to encourage students to explain what is occurring. Demonstrations provide highly structured situations in which many students can be called on to be involved in the learning environment. The demonstrations in this manual contain **prompts** and **cues** for involving students in this form of activity, permitting them to inquire into the nature of matter and energy.

CONDUCTING LABORATORY EXERCISES

There are many pluses for laboratory instruction. For students, laboratory investigations permit them to participate in the scientific enterprise. This helps them to develop intellectual skills, and guide them to find answers to questions. The laboratory helps reinforce knowledge that is stressed in the classroom and textbook. Laboratory exercises can also help develop a positive attitude toward science.

Laboratory instruction can make science teachers successful since it has the potential to produce positive learning outcomes. In addition, science teachers who are effective with laboratory teaching are popular among students and are generally highly regarded by their supervisors.

Along with the pluses, there are some minuses associated with laboratory instruction. Laboratory exercises take more time to prepare than lectures and discussions. You must gather the necessary equipment from your storage room or the storage room in other science teachers' rooms. In some instances, you may have to purchase materials in a hardware or drug store. You have to check equipment to see if it is in proper working condition--all of which is time consuming.

Managing student activity and discipline can also be a problem during laboratory work. Some students misbehave and are unproductive during laboratory instruction. These situations can cause you to question the value of this type of instruction and to de-emphasize it in your teaching. Consequently, we have provided information in this manual to assist you in identifying and preparing the equipment and materials that you will need for each laboratory. We have also made a great effort to help you understand each laboratory -- the science behind it and how to conduct it -- so that it will be a successful learning experience for everyone involved.

Recommendations for laboratory instruction:

- Use laboratory exercises frequently in your courses.
- Employ a variety of laboratory exercises in your teaching such as inductive, deductive, science process skill, technical skill, and exploratory laboratories.
- Keep the hands-on portion of laboratories short so it does not consume too much time.
- Spend adequate time on prelaboratory discussions so that all students know what to do in the laboratory and are not preoccupied with reading directions and figuring out what comes next.
- Conduct thorough postlaboratory discussions so that the knowledge and skills related to the laboratory reinforce the learning outcomes of the unit under study.
- Keep recording and reporting laboratory results as simple as possible to maximize student interest in laboratory work and ensure economy of time.
- Carefully monitor students' activities during laboratory activities, urging them to work quickly and safely.

The prelaboratory discussion. Preparing students for the laboratory cannot be overemphasized. Youngsters need a thorough orientation for laboratory work, otherwise they are unproductive and waste time. A good prelaboratory discussion will inform students on why, how, and what they will be doing. It provides a mind-set which will get students involved in the hands-on part of laboratory work and inform them on how to work quickly and effectively.

The first step is to inform the students of the purpose of the laboratory. They need to know why they are doing the laboratory and how it fits into what they are studying in the classroom. Give them some idea of what to look for, without giving them the answers. The laboratory should be structured so that the students must do the lab in order to achieve the objectives of the learning exercise. If students know the answers to the questions on the laboratory work sheet, they will often attempt to avoid doing the laboratory exercise.

To be sure that all class members understand the purpose of a given laboratory exercise, call on several students in the class to give the purpose of the laboratory and what they are trying to accomplish.

Teacher: Marsha, what will you be looking for in this lab today?
Student: I want to see how many corks I can float on this piece of tin foil.
Teacher: Why is the number of corks so important?
Student: It has something to do with density, I guess.
Teacher: Bill, can you help us with the answer?
Student: Well, the formula for density is mass per unit volume, and the number of corks is related to the mass.
Teacher: Very good, Bill. Don, will you go to the chalkboard and write the formula for density and indicate which symbols relate to the materials that you will be using today.

$D = m/v$
m = mass of object
v = volume of object

Teacher: Thanks, Don. Marleen, are these labels correct?

This vignette illustrates the type of interaction that could take place during a prelaboratory discussion. We cannot overemphasize the amount of interaction that should occur in order to feel confident that every student knows the purpose of the laboratory. You must call on many students to achieve this end and ask probing questions to ensure understanding. Furthermore, this gives you an opportunity to reinforce students for participating and responding. Remember, one of the goals of this manual is to help physical science teachers promote a positive learning environment where students feel good about themselves and enjoy science.

The second step in the prelaboratory discussion is to provide procedural directions. These directions tell students how to get and return equipment, and how to perform certain manipulative procedures.

Teacher: Please look at the chalkboard and study my diagram and statement on how to hook up the voltmeter in this series circuit.
Teacher: Ann, would you go to the front table and hook up this voltmeter to this circuit?
Teacher: Jose, did Ann hook up the voltmeter properly?
Student: Yes.
Teacher: Jose, give us the rule for hooking up voltmeters to electric circuits?
Student: The meter should be hooked across the power source or the load.
Teacher: That is right. Ann and Jose are correct in connecting the voltmeter across the power source.

Again, we emphasis the importance of **calling on students** in the class to be sure they understand directions and procedures. Call students to the front of the class to demonstrate procedures and techniques. Ask them to verbalize what it is they are expected to do.

The postlaboratory discussion. The postlaboratory discussion goes beyond reviewing the results of the laboratory. It is an opportunity to reinforce the major instructional objectives of the unit under study. The postlaboratory discussion, when conducted properly, provides students with new insights into what they are studying and greater understanding of the scientific enterprise. Those who wish to improve student learning through a hands-on, laboratory-based physical science course must be thorough in the concluding phase of laboratory work so that students will internalize new information and skills, and be able to demonstrate these on examinations.

On one hand, we are advising you to frequently conduct laboratory activities, and to make them short so they do not consume too much course time. On the other hand, we are advising you to conduct postlaboratory discussions that are thorough and which may take a considerable amount of time to complete. This advice may sound foolish. Our reasoning is that if you spend too much time on the hands-on segment of each laboratory exercise, say two or more class periods for each laboratory, you will involve your students in few labs and little other instruction.

The postlaboratory discussion should be a recitation, lecture, discussion, and review session. Although, the postlab follows the laboratory activity, it should fit with other aspects of the course. Postlaboratory discussions may extend beyond a half period of instruction into one or more periods. The ideas from each laboratory may be discussed during the remainder of the unit of study.

You may wish to collect and grade the laboratory sheets or reports from students before you conduct the postlaboratory discussion. This procedure will provide you with information about how well the class performed on a given laboratory. You will then be prepared to discuss the procedures and results, and to elaborate on areas which need emphasis.

PAPER AND PENCIL EXERCISES

Along with a great deal of oral interaction in the classroom, paper and pencil exercises are highly recommended. The more often students write down their thoughts, the better they will understand the subject you are teaching. Writing down answers to questions and explaining ideas in complete sentences improves learning and retention. For these reasons, we have included many paper and pencil exercises with each unit in this instructional manual and recommend that you use them frequently in your teaching.

We observed that effective teachers use a variety of teaching aids and instructional strategies to improve learning, which include writing ideas down on paper. Consequently, you should request students in your science classes to put their thoughts into writing. Ask them to describe events and explain phenomena in their own words. This activity will require them to recall key concepts and major ideas that you stressed in your lectures, discussions, demonstrations, and laboratories. After you have illustrated concepts, laws, and principles through concrete means, require students to internalize these ideas through writing. Constructing complete sentences and coherent paragraphs is cognitively more demanding than just giving oral explanations, but this type of mental activity pays off on tests.

In addition to the paper and pencil exercises provided in this manual, we encourage you to construct some of your own. Keep these exercises short and use them frequently. Remember, doing and explaining provide a powerful approach to instruction.

QUESTIONING

A major strategy for improving the quality of science teaching is through questioning. By asking questions, we can get students involved and interested in "finding out". This approach requires a skilled teacher who calls on many students to respond and who provides plenty of time for students to explain thoroughly. Good questioners get others to think and inquire because they provoke thought, probe for meaning, and pause for certain periods of time to allow for reflection. In contrast, the unskilled teacher asks few questions in rapid fire order and then moves on with the lecture.

Planning questions. The first step is to plan in advance the questions that you wish to ask . Write these questions down on paper and place them in front of you for reference during your lecture or discussion. This manual provides hundreds of questions which can be used during science instruction. These questions appear in the paper and pencil exercises in each unit. They appear throughout the demonstrations, and numerous questions appear in the teacher's version of each laboratory exercise, especially in the pre- and postlaboratory discussion. In the event that you develop your own instructional activities or improvise on those in this manual, place the questions within your text when you construct it.

Lower and higher order questions. You can improve classroom discussion by using both lower and higher order questions. Bloom's Taxonomy of Cognitive Objectives is a useful conceptual tool for this purpose (see the table below). On this six-level taxonomy, the first two levels--knowledge and comprehension--represent lower order cognitive activity. Levels three through six--application, analysis, synthesis, and evaluation--represent higher order cognitive activity. Each level of question has its place in science teaching and one type should not be used to the exclusion of the other. Too often, however, we ask too many factually oriented and recall questions. We should reduce the proportion of knowledge level questions and increase the proportion of questions which require analysis and application of knowledge.

A Taxonomy for Constructing Classroom Questions:

Level	Cognitive activity	Key concepts
1 Knowledge	Remember, recall or recognize facts, ideas, information, or principles as they were taught.	Knowledge, recall, memory
2 Comprehension	Comprehend, interpret, or translate information or ideas.	Describe, explain, illustrate
3 Application	Solve problems, find solutions, and determine answers through the application of rules, principles, or laws.	Application, solution, determination
4 Analyze	Distinguish parts from whole, identify causes, find support and evidence, construct hypotheses, and draw conclusions.	Reason, think logically, induce, deduce
5 Synthesize	Produce, design, make and construct products. Synthesize ideas, produce ways and determine how to......	Make, produce, create, write
6 Evaluation	Judge, appraise, assess, or criticize on the basis of criteria.	Evaluate, judge, critique, substantiate.

Pausing and waiting. A major factor which has been found to improve the quality of interaction and achievement is **wait time**. Wait time is the interval between the time the teacher asks a question and a student is called upon to respond to that question. In other words, it is the time a student is given to think about an answer to a question. Generally, the wait time in most classrooms is very short--about one second. Yes, this is all the time we usually give our students to think about the answer to a question and to begin responding.

Many teachers ask lower order questions in rapid fire order. Melnik (1968) reported that some teachers ask as many as 150 questions per class hour. When one considers that there are only 60 minutes in a period and many other activities occur during the period--taking roll, teacher directions, writing on the chalkboard, students responding to questions--that is a lot of questions to ask in such a short time.

Tobin and Capie are two science educators who have studied what goes on in classrooms and how this interaction influences science learning. They (Tobin & Capie, 1984) report that teachers who ask clear questions and utilize an average wait time, greater than **three seconds,** improve student achievement. An example of a question in which the teacher pauses more than three seconds before calling on a student to respond is as follows:

Teacher: After observing what sodium hydroxide did to this gob of lard, what would it do to your skin?

Pause: 4.5 seconds

Teacher: Barbara, can you tell us what would happen?

Student: I think the sodium hydroxide would burn your skin.

Tobin and Capie (1984, p. 221) offer the following recommendations for improving the quality of dialogue and student engagement in your classroom:

1. A question is clearly presented at a relevant time during the lesson.
2. All students are given three to five seconds of silence in which to consider a response.
3. One student is called on to respond to the question.
4. The student is provided three to five seconds to commence a response. If the student does not respond, the question is repeated, rephrased, or redirected to another student.
5. After a response to a question, three to five seconds are provided for the student to commence to elaborate or evaluate the response and for others in the class to consider the appropriateness of the response.
6. The question or the response is redirected to another student in the class. The redirecting strategy may be utilized for a maximum of three to four occasions.

In addition to wait time, redirect questions and call on many students. This is how to involve the entire class in the learning environment and to keep them on task. When students are called upon to respond, they have to think, which causes reinforcement of learning. Create a classroom environment where students are busy thinking, reasoning, justifying, and explaining. Yes, make them "turn their computers on". When you develop this type of classroom, the students will enjoy science and do well.

TARGET STUDENTS

Researchers who study classroom interaction report a common occurrence that takes place in most classrooms, which helps to explain why many students are left out of the learning process. Most teachers call on only a limited number of students in the class to answer questions. These students are called "target students" and they seem to dominate classroom discussion (Tobin & Gallagher, 1987). In every classroom, there are some students who want to respond and generally respond well to teacher questions. They tend to be high achievers and to thrive on the challenge of answering the more difficult questions.

When classroom discussion centers on only a few or a handful of students, chances are that other students are only minimally involved in the learning situation--no wonder many students do poorly in science. How can youngsters get turned on to science if they are being left out of important discussions? It appears that science course experiences are an elitist experience where only the brighter students are receiving attention from the teacher.

We cannot emphasize too strongly that the science instructional model stressed in this manual is to get all of the students involved in discussions. Make all the students feel they are intensely involved in their science course, and that they can explain concepts and principles. Let's "target" all of our students to be participants and winners in our classes.

RESULTS FROM THE CLASSROOM

Approximately 20 physical science teachers volunteered to try out the activities and emphasize the teaching tips suggested in this manual during its development. They were eager to use some of the demonstrations and laboratory exercises, and to emphasize selected teaching skills in their classrooms with the expectation that they might increase student interest and achievement in physical science.

The only requirement for participation in this project was that each teacher: (1) identify at least two equivalent classes of students, (2) randomly select one class in which to use the manual, leaving the other to instruct as usual, and (3) collect perception and achievement data from both classes at least twice -- once for the baseline scores and a second time to determine how much effect this approach had on the treatment class. Although these physical science teachers taught in many different school districts, their teaching situations were similar in many respects. Their curricula addressed almost the same physical science topics. Their school years were divided into six marking periods. Students were given a numerical grade at the conclusion of each six weeks. These courses stressed chemistry for one semester and physics the other semester.

Jan Bennett (not the teacher's real name) is one of the physical science teachers who tried out some of the activities and participated in the data collection. She has been teaching for many years and has a strong background in biology. Only recently, Ms. Bennett has been assigned to teach physical science. She teaches science to students who have problems functioning in regular classrooms. Jan Bennett collected data from one of her regular classes (control) and from a treatment class (experimental), which received the teaching strategies and activites in this manual, at the end of three six-week marking periods.

It took Ms. Bennett months before she got the treatment class to outperform the regular class in achievement and for the treatment class to report consistently positive attitudes toward their physical science class. At the end of the third six-week grading period, the two groups had mixed results. On some of the items, the control indicated a higher interest in physical science than the experimental group; while on other items, the experimental group had higher interest scores. However, the experimental group had higher six-week grades. Similar results were produced during the fourth six weeks of data collection. The results were discussed with Ms. Bennett and it seems she used some of the activities and teaching tips from the manual with the regular class, which again accounted for these mixed results. During the fifth six weeks that she implemented these ideas and acitivities, however the experimental group outperformed the control on practically every item on the questionnaire to which the students responded (see this questionnaire in Appendix A).

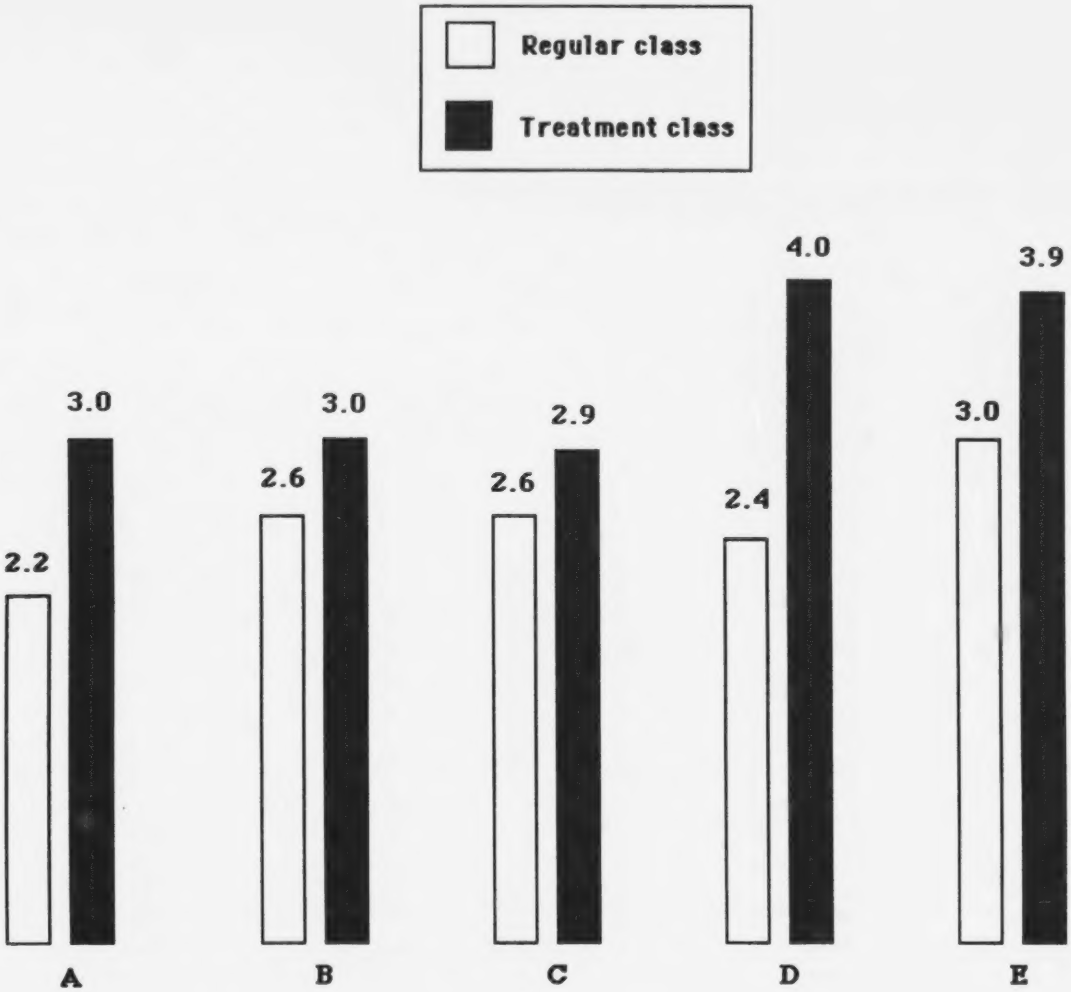
If you study the bar graphs in Figure 1 you will see that the students in the treatment class enjoyed their physical science class more than students in the regular class (A). Furthermore, these students believed that the information that they were acquiring was more useful (B). They felt more comfortable in their science class than the students in the regular class (C). When they were asked to rate two of the most important objectives of this project, they indicated emphatically that "they enjoyed the course"(D) and "they learned a lot"(E).

In addition, the treatment class had higher grade averages (78.6, 80.3, and 87.00) for the three six-week grading periods when data was collected than the regular class (70.7, 75.3 and 74.0). The former outperformed the latter by a whopping 13 grade points in the fifth grading period (see H in Figure 2). This is an extraordinary accomplishment when you consider that average grades in physical science classes are often in the low 70s.

The outcomes are explainable when you look at the results (Figure 3) on the set of six questions regarding what students reported actually took place in their classrooms regarding the teaching skills that Jan Bennett used (I). The students in the treatment class indicated on their questionnaires that Ms. Bennett stressed the teaching skills recommended in this manual more in their class than she did in the regular class. The areas that were stressed are: asking questions, explaining ideas, thinking, learning the demonstrations, and using paper and pencil exercises.

Figure 1

Comparison of Regular and Treatment Classes On Perception of Course



A. How much do you enjoy this science class?

B. How useful is the information taught in this course?

C. How did you feel in science classs?

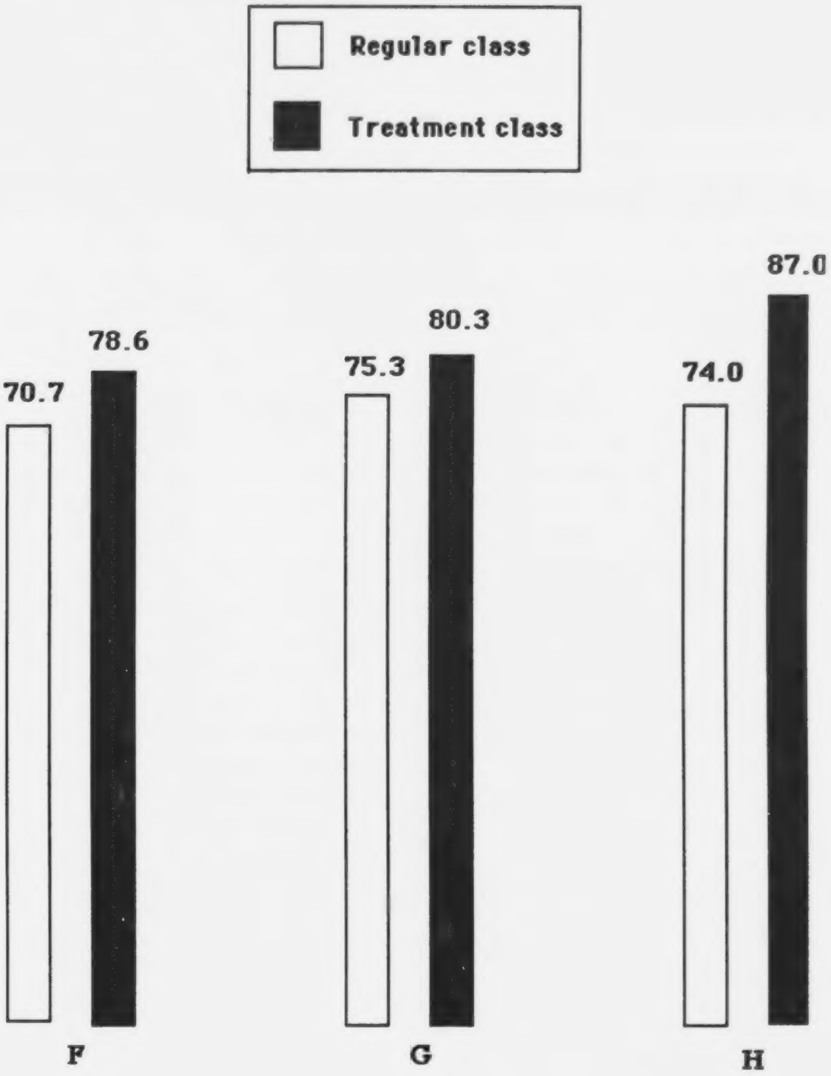
D. I enjoyed this course.

E. I learned a lot during this course.

(Range of Scores for Items A thru E = 0-4)

Figure 2

Comparison of Regular and Treatment Classes On Achievement



F. Third six-week grading period

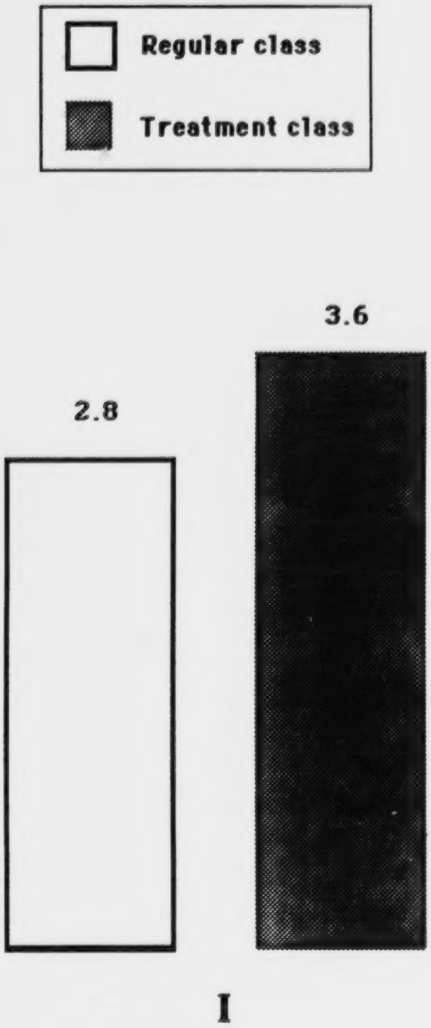
G. Fourth six-week grading period

H. Fifth six-week grading period

(Range of F thru H = 0-100)

Figure 3

Comparison of Regular and Treatment Classes On the Teaching that Took Place



I. What took place in the classroom?

(Range of scores for I = 0-4)

When this teacher stressed the instructional strategies and teaching skills discussed in this section, the results were tremendous. Improved interest and achievement were observed, just as they have been reported by researchers and educators who have promoted these ideas and activities. Furthermore, many other physical science teachers participating in this project increased students' attitude toward physical science and increased their achievement. They were able to do this in the first six weeks in which they used these ideas and activities. However, we believe the most dramatic and long lasting improvements will come when these ideas are implemented over many grading periods and where the teacher considers the feedback of the students regarding what they believe about their course and classroom. We also believe that physical science teachers who transmit these ideas into their classes will cause many students to say at the end of their courses:

"I enjoyed this science class and I learned a lot."

References

Collette, A. T. & Chiappetta, E. L. (1986). Science instruction in the middle and secondary schools. Columbus, Ohio: Charles E. Merrill Pub. Co.

George, P. & Lawrence, G. (1982). Handbook for middle school teaching. Dallas, Scott Foresman & Co.

Hueftle, S. J., Rakow,S. J., & Welch, W.W. (1983). Images of science: A summary of results from the 1981-82 National Assessment in Science. Minnesota Research and Evaluation Center, University of Minnesota.

Melnik, A. (1968). Questions: An instructional-diagnostic tool. Journal of Reading, 11: 509.

Roadrangka, V. & Yeany, R. H. (1985). A study of the relationships among type and quality of implementation of science teaching strategy, student formal reasoning ability, and student engagement. Journal of Research in Science Teaching, 22(8), 743-760.

Tobin, K. & Capie, W. (1984). Relationships between classroom processes and science learning. In C. W. Anderson (Ed.), 1984 AETS Yearbook, Observing Science Classrooms: Observing Science Perspectives and Practices, edited by Charles W. Anderson. Ohio State University, ERIC Clearinghouse for Science and Mathematics.

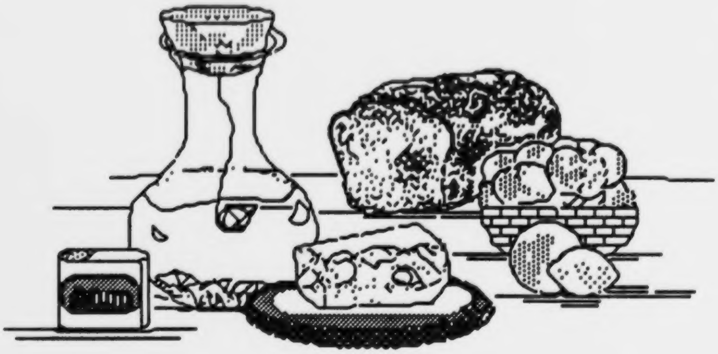
Tobin, K. & Gallagher, J.J. (1987). The role of target students in the science classroom. Journal of Research in Science Teaching, 24 (1), 61-76.

Wise, K. C., & Okey, J. R. (1983). A meta-analysis of the effects of various teaching strategies on achievement. Journal of Research in Science Teaching, 20(5), 419-436.

Turning Students on to Chemistry

2

Background Information



Most youngsters are fascinated with chemistry. They like to find out what happens when you mix chemicals, why things stick together, and how to break up matter. The chemistry section of physical science is a great place to interest students in science and to give them the impression that they can understand their environment. This topic provides an opportunity to reinforce the importance of science and how much fun it is to study.

This unit contains many demonstrations and laboratory activities that are easy to do and that students will enjoy. If you analyze this unit, you will note that the activities are:

- easy to perform,
- require few chemicals,
- relevant to everyday life, and
- qualitative rather than quantitative in nature.

In addition to using the activities in this unit to create interest in physical science, these activities are instructive as well. They introduce students to basic terminology such as that related to acids, bases and proteins. They also help youngsters develop basic laboratory techniques.

The instructional activities in this unit can be used in at least two ways. They can be used to help students become acquainted with chemistry and to begin their study of this discipline. They can also be used intermittently throughout the study of chemistry to illustrate specific points, to introduce certain topics, or to get students' attention. In any case, use these demonstrations and laboratory exercises to get students excited about physical science, convincing them that science is fun and a worthwhile endeavor.

REMEMBER, as you begin the study of chemistry with these activities, get all of the students involved. Ask many questions, and provide students with time to think and respond in a thorough manner. Make the students feel special and to believe they are acquiring knowledge that is important in their lives, regardless of the careers they choose to pursue.

INGREDIENTS

Paper and Pencil Exercise

-- for the student --

PURPOSE

In this activity you are asked to find nutritional information on the label of a packaged or a canned food product.

DIRECTIONS

Examine the label of the food product you have selected or were assigned to analyze, and answer the following questions:

1. What is the name of the product? ______________________________

2. What is the net weight of the contents? ______________________________

3. What is the major ingredient of the product? ______________________________

4. List all of the ingredients in the product.

____

____

____

____

5. List the nutrition information per serving.

____

____

____

____

6. If you were on a salt-free diet, could you eat this product? ______________

7. Are there any ingredients in this product that some people might be allergic to? ________

A CHECKLIST OF FOOD ADDITIVES

Paper and Pencil Exercise

-- for the student --

Examine the ingredients of food products that are canned or packaged. Find out what additives are present in these foods. Below is a list of additives that you can check for and determine how much is added to each food. Five columns are provided so that you can indicate how much of a given additive is in each of at least five foods. We recommend that you extend the columns to the right and examine five more foods so that you analyze at least 10 food products.

Additive	Food Product				
	__________	__________	__________	__________	__________
ascorbic acid	_____	_____	_____	_____	_____
baking soda	_____	_____	_____	_____	_____
benzoic acid	_____	_____	_____	_____	_____
BKA	_____	_____	_____	_____	_____
BKT	_____	_____	_____	_____	_____
calcium	_____	_____	_____	_____	_____
caramel	_____	_____	_____	_____	_____
carrageenan	_____	_____	_____	_____	_____
citric acid	_____	_____	_____	_____	_____
corn syrup	_____	_____	_____	_____	_____
dextrin	_____	_____	_____	_____	_____
dextrose	_____	_____	_____	_____	_____
diglycerides	_____	_____	_____	_____	_____
disodium - EDTA	_____	_____	_____	_____	_____
erythorbic acid	_____	_____	_____	_____	_____
flavorings	_____	_____	_____	_____	_____
gelatin	_____	_____	_____	_____	_____
glutamic acid	_____	_____	_____	_____	_____
guar gum	_____	_____	_____	_____	_____
honey	_____	_____	_____	_____	_____
hydrolyzed vegetable protein	_____	_____	_____	_____	_____
iodine	_____	_____	_____	_____	_____
iron	_____	_____	_____	_____	_____

Additive	Food Product				
lecithin					
methyl cellulose					
minerals					
monoglycerides					
mustard					
MSG					
nitrates					
nitrites					
pectin					
pepper					
polysorbate					
potassium - propionate					
propylene					
riboflavin					
saccharin					
saffron					
salt					
salt substitute					
silicates					
silicon dioxide					
sodium - sorbates					
sorbitol					
spices					
starch					
sucrose					
sugar					
tricalcium phosphate					
yeast					
vinegar					

Additive	Food Product				
	________	________	________	________	________
vitamins	____	____	____	____	____
OTHERS	____	____	____	____	____
Total	-----	-----	-----	-----	-----

1. Total the additives in each food column.

2. According to your data, what are the three most abundantly used additives?

   ____

3. Which product contains the greatest number of additives?

   ____

4. Which product used the least additives?

   ____

5. Do you prefer foods with or without additives? __________ Give reasons for your answer.

   ____

   ____

   ____

6. What were some of the methods used to preserve food before refrigerators were common and chemical preservatives were added?

   ____

   ____

7. Besides preserving food, what are some other reasons that additives are put into food?

   ____

   ____

   ____

EAT YOUR CEREAL. IT'S GOOD FOR YOU!

Demonstration

PURPOSE

In this activity, students can observe the "unseeable" amount of elemental iron that is present in various breakfast cereals.

MATERIALS

Breakfast cereals (Use those that are iron fortified)
500 ml beaker
Distilled water
Magnetic stirrer

BACKGROUND

Many people teach children that breakfast is the most important meal of the day. And it is! But are cereals really our best breakfast food?

Cereals contain many different nutrients. Some cereals are vitamin fortified while others are high in fiber and other natural foods. The list of food additives in cereals is quite long. Fortunately, many people are interested in nutrition, diet, and the contents of the food they eat. More people are beginning to take seriously the phrase "you are what you eat".

PROCEDURE

1. Obtain three different cereals.

2. Weigh out about 50 grams of one cereal.

3. Place the cereal in the beaker and add about 300 ml of the distilled water.

4. Place the magnetic stirrer bar in the beaker.

5. Place the beaker on the stirrer and stir for about 20-25 minutes. (A magnetic stirrer with a built in heating element does help improve your results.)

6. Carefully remove the magnetic stirrer bar and have students examine it for iron filings.

QUESTIONS

1. What did you observe on the magnetic rod? (Iron filings.)

2. Do you think your body can use this iron? (Only if it is changed into some other form of iron through a chemical change such as to iron salts.)

3. How did the amount of iron from each cereal compare? (The amount of iron should be different if iron content varies.)

SUGGESTED ACTIVITY

Stomach acid is dilute HCl. Interested students might place the stirring bar in approximately 100 mL of dilute hydrochloric acid, stir for 30 minutes, and try to determine if the iron dissolves.

CAUTION! Do not allow contact with skin, eyes, clothing, etc. Wash with plenty of water if accidental contact with HCl occurs.

AN APPLE A DAY ...
Demonstration

PURPOSE

The purpose of this demonstration is to show that cooking breaks down the cells in food. Thus, processes which breakdown cells, "cook" the food.

MATERIALS

1 dozen apples
Refrigerator freezer
Blender
Hot plate
Cooking utensils

PROCEDURE

1. Freeze half of the apples in advance.
2. Allow the frozen apples to thaw.
3. Prepare the other apples by boiling.
4. Process both sets of apples in a blender so that they are the same consistency.
5. Serve some of each preparation to the students.

QUESTIONS

1. Can you tell the difference between the two preparations? (Students should not be able to tell the difference between the cooked and frozen apples -- both processes break down the cell wall of plant tissues.)
2. Does "cooking" always require heat? (No)
3. What do you think happens to the apples when they are cooked? (The cell walls of the apples are destroyed.)

REMEMBER -- Get as many students involved as possible during science instruction. Call on students who usually participate very little in classroom discussion.

RUBBER BONES
Demonstration

PURPOSE

To observe the properties of bone after the minerals have been removed.

MATERIALS

Chicken or turkey thigh bone
1000 ml beaker
Safety goggles
Acetic acid (dilute solution)
Glass plate
Baking soda
600 ml beaker
Balance
Tongs

PROCEDURE

1. Put the bone in a 1000 ml beaker.

2. Pour enough acetic acid into the beaker to just cover the bone. Cover the beaker with a glass plate.

3. Leave the bone in the beaker for several days.

4. Prepare a solution of baking soda by adding 1 gram of baking soda to 500 ml of water in a 600 ml beaker.

5. With tongs remove the bone and rinse it in the baking soda solution. Run the bone under cold water for several minutes. The baking soda, which is a weak base, neutralizes the acetic acid and stops the breakdown of the bone tissue.

DISCUSSION

1. Ask the students to describe the condition of the bone. How does it differ from before it was soaked in the acetic acid? (It is now soft and flexible.)

2. What minerals do you think were removed from the bone? (Minerals containing calcium.)

INVESTIGATING PROTEOLYTIC ENZYMES

Laboratory Exercise

-- for the teacher --

PURPOSE

This laboratory exercise illustrates the activity of proteolytic enzymes on protein in food. You will observe how proteins are broken down and how some enzymes work.

MATERIALS

Meat tenderizer
Gelatin
Pineapple, fresh
Ice
Beakers
Plastic pans
Evaporating dishes
Stirring rod

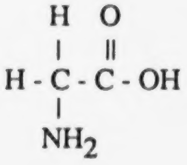
BACKGROUND

Meat tenderizers are members of a class of compound called proteolytic enzymes. Some common examples are bromelain, papain, and ficin. All of these enzymes are produced by plants. Bromelain is found in pineapple. Papain is found in papaya. Ficin is found in fig tree sap. Besides being used as a meat tenderizer, ficin has several other uses: a coagulant in cheese making, bating leather, shrink-proofing wool, and as a spot remover.

As meat tenderizes, proteolytic enzymes aid in the breakup of proteins. Proteins decompose to form amino acids in a process called hydrolysis. This process requires an enzyme to speed it up.

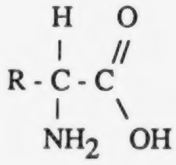
$$\text{Proteins} \quad \underset{-H_2O\ (\text{formation})}{\overset{+H_2O\ (\text{digestion})}{\rightleftharpoons}} \quad \text{amino acids}$$

Amino acids have the general formula:



$$\begin{array}{ccccc} & H & & O & \\ & | & & \| & \\ H - & C & - & C & - OH \\ & | & & & \\ & NH_2 & & & \end{array}$$

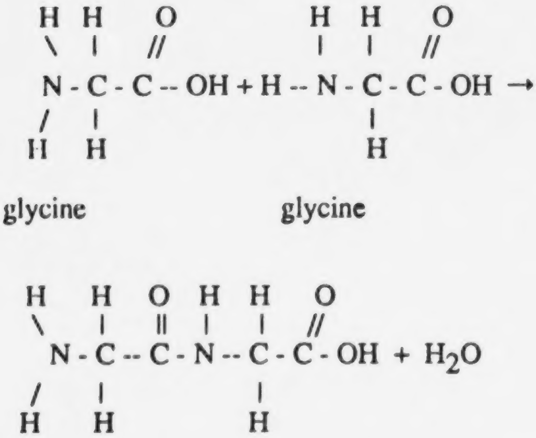
glycine



$$\begin{array}{cccc} & H & & O \\ & | & & // \\ R - & C & - & C \\ & | & & \backslash \\ & NH_2 & & OH \end{array}$$

general formula of amino acids

When one amino acid combines with another amino acid they lose a molecule of water and form a peptide bond.



$$\mathrm{H_2N{-}CH_2{-}C(=O){-}OH + H{-}NH{-}CH_2{-}C(=O){-}OH \rightarrow H_2N{-}CH_2{-}C(=O){-}NH{-}CH_2{-}C(=O){-}OH + H_2O}$$

glycine glycine

peptide bond glycylglycine

The tenderizing of the meat protein is the reverse of this reaction. Also, keep in mind that heat destroys the proteolytic enzymes; therefore, once the cooking process begins the tenderizer has no more effect.

Notice that the hydrolysis reaction, which breaks up the protein molecules, uses up water. Nevertheless, when the students do the lab, using gelatin it will appear that water is actually produced because the gelatin becomes liquefied where the tenderizer acts upon it.

When the gelatin is formed, large protein molecules result which trap water molecules, like mice in a cage. When the tenderizer breaks up the protein molecules the trapped water molecules are freed. Only a small portion of free water molecules are used in the hydrolysis reaction.

PRELABORATORY DISCUSSION

1. What is a chemical bond?

Answer -- The glue that holds the atoms together.

2. What is a catalyst?

Answer -- Something that changes the rate (speed) of a reaction. The catalyst itself is not changed.

3. What is hydrolysis?

Answer -- A reaction where molecules are broken apart and water molecules (hydro) are used in the pieces.

PROCEDURE 1: Papain

1. Following the directions on the package, prepare one cup of gelatin.
2. While still hot, pour an equal amount into each of the evaporating dishes.
3. Sprinkle meat tenderizer on top of the hot gelatin in the first dish.
4. Place both dishes in a large trough filled with ice until the gelatin is solidified (about 15 minutes).

CAUTION: Do not eat any of this gelatin. The beakers and evaporating dishes may have been contaminated with poisonous chemicals when used in previous lab exercises.

5. After cooling, sprinkle some meat tenderizer over the top of the gelatin in the second dish.

6. Observe the gelatin in both dishes for 5-10 minutes. Note any changes or differences in the gelatin. Press down on top of the gelatin with your finger or a stirring rod.

PROCEDURE 2: Bromelain

1. Obtain a FRESH pineapple from your local grocery store.
2. Using the extra gelatin from procedure 1, fill another evaporating dish.
3. Cut a slice of pineapple and place it on the solid gelatin.
4. Observe and record your observation just as you did in procedure 1.
5. Clean and dispose of all the gelatin as instructed by your teacher.

SUMMARY QUESTIONS

1. How do the enzymes react with the protein in gelatin?

Answer -- They break apart the bonds in the protein - hydrolysis.

2. In part 1, what effect did the high temperature have on the enzyme papain?

Answer -- The extra heat causes the enzyme to be inactive.

3. How did the fresh pineapple react with the protein in gelatin?

Answer -- It liquefies the gelatin.

4. When making a congealed salad for dinner, would you add fresh pineapple? Explain.

Answer -- No. It would cause the salad to liquefy.

5. Could you make a congealed salad from canned pineapples?

Answer -- Yes. The heat from canning destroys the enzyme.

6. While barbecuing a steak, is it a good idea to put tenderizer on the meat while it is cooking?

Answer -- No. The heat will extinguish the effect of the meat tenderizer.

CONCLUSIONS

Write a summary paragraph on how meat can be tenderized.

Answer -- It can be tenderized by the action of plant enzymes, if they are used before heating.

POSTLABORATORY DISCUSSION

1. Describe some old wives tale methods for meat tenderizing.

Answer -- Some people believe that beer or lemon juice can be used to tenderize food. Although these products do impart some flavor, they contain no proteolytic enzymes and therefore do not break down the proteins chemically.

2. Describe some of the possible side effects of eating too much fresh pineapple or figs.

Answer -- These foods contain enzymes which act on tissue protein and they can cause irritation of the mouth and stomach.

INVESTIGATING PROTEOLYTIC ENZYMES

Laboratory Exercise
-- for the student --

PURPOSE

This laboratory exercise illustrates the activity of proteolytic enzymes on protein in food. You will observe how proteins are broken down and how some enzymes work.

MATERIALS

Meat tenderizer
Gelatin
Pineapple, fresh
Ice
Beakers
Plastic pans
Evaporating dishes
Stirring rod

PROCEDURE 1: Papain

1. Following the directions on the package, prepare one cup of gelatin.
2. While still hot, pour an equal amount into each of the evaporating dishes.
3. Sprinkle meat tenderizer on top of the hot gelatin in the first dish.
4. Place both dishes in a large trough filled with ice until the gelatin is solidified (about 15 minutes).

CAUTION: Do not eat any of this gelatin. The beakers and evaporating dishes may have been contaminated with poisonous chemicals when used in previous lab exercises.

5. After cooling, sprinkle some meat tenderizer over the top of the gelatin in the second dish.
6. Observe the gelatin in both dishes for 5-10 minutes. Note any changes or differences in the gelatin. Press down on top of the gelatin with your finger or a stirring rod.

PROCEDURE 2: Bromelain

1. Obtain a FRESH pineapple from your local grocery store.
2. Using the extra gelatin from procedure 1, fill another evaporating dish.
3. Cut a slice of pineapple and place it on the solid gelatin.
4. Observe and record your observation just as you did in procedure 1.
5. Clean and dispose of all the gelatin as instructed by your teacher.

SUMMARY QUESTIONS

1. How do the enzymes react with the protein in gelatin?

____

____

____

2. In part 1, what effect did the high temperature have on the enzyme papain?

3. How did the fresh pineapple react with the protein in gelatin?

4. When making a congealed salad for dinner, would you add fresh pineapple? Explain.

5. Could you make a congealed salad from canned pineapples?

6. While barbecueing a steak, is it a good idea to put tenderizer on the meat while it is cooking?

CONCLUSIONS

Write a summary paragraph on how meat can be tenderized.

THE CHEMISTRY OF BRUISED FRUIT

Laboratory Exercise

-- for the teacher --

PURPOSE

The purpose of this investigation is to study the effect that oxygen has on peeled or bruised fruit.

MATERIALS

Vitamin C tablets
Fruit juices
Fresh fruit
Any retail "Fruit Fresh"
Test tubes
Stoppers

BACKGROUND

Oxidative enzymes are chemicals that catalyze oxidation-reduction reactions. These enzymes are found in the cells of fruit. They react with oxygen to decompose the cells of the fruit. This causes the darkening of the fruit.

Vitamin C, also called ascorbic acid, is an important nutrient for human beings. It is found in many citrus fruits and is used as a preservative or nutrient supplement in many foods. Vitamin C is a reducing agent. It belongs to the family of chemicals called antioxidants. As an antioxidant, vitamin C reacts with the oxidative enzymes in the fruit cell before they can destroy the fruit cell. The molecular formula for ascorbic acid is $C_6H_8O_6$.

PRELABORATORY DISCUSSION

1. What is oxidation?
Answer -- Oxidation is the loss of electrons.
2. Name two good sources of Vitamin C.
Answer -- Fresh fruits and fruit juices.
3. What is reduction?
Answer -- Reduction is the gain of electrons.
4. Describe how fruit changes in appearance and taste when it is bruised.
Answer -- Bruised fruit turns brown and sometimes tastes sour or rotten.

PROCEDURE 1:

1. Before beginning procedure 2, each lab group should prepare the following six test tubes:

Test Tube	Color of Fruit	Observations
#1 empty		
#2 empty		
#3 1/2 filled with water		
#4 Full with boiled water		
#5 1/2 filled with vitamin C solution		
#6 1/2 filled with fruit juice		

PROCEDURE 2:

1. Slice an unpeeled apple or pear into six or more pieces. (It is sometimes easier for the teacher to cut the fruit for all the students.)
2. Bruise each piece of fruit by smashing them with your thumb.
3. Quickly place a bruised slice into each test tube. Stopper all test tubes except #1.
4. Wait 25 minutes, then empty the test tubes and make observations on the color of each slice.

PROCEDURE 3: To be done by the teacher.

1. At the beginning of class place several bruised slices of fruit into a solution of store bought fruit fresh.
2. After the 25 minutes, empty the fruit fresh and examine the slices.

SUMMARY QUESTIONS

1. How does the fruit slice in test tube #1 compare to the others?

Answer -- It should be darker in color.

2. How does the fruit slice in the fruit juice compare to that in the vitamin C solution?

Answer -- They should be about the same color.

3. How does mother nature protect her fruit from the oxidative enzymes?

Answer -- Apples and pears have protective peels or skins.

4. If you make a fruit salad, how does squirting it with lemon or lime juice help prevent browning?

Answer -- Lemon and lime juice contain vitamin C.

CONCLUSION

Write a brief summary statement on how fruit is changed by bruising and exposure to air.

POSTLABORATORY DISCUSSION

1. Would heating or cooking the fruit change its reaction to bruising?

Answer -- Cooking will destroy the oxidative enzymes and therefore decrease the darkening.

2. Is fruit fresh added to all store bought canned fruits?

Answer -- Almost all canned fruits will contain some fruit fresh.

3. Is the darkening of a fruit in any way related to how human skin is darkened by tanning or forming freckles?

Answer -- It is believed that these enzymes that darken fruit also will produce melanin or the pigment of the skin.

REMEMBER -- This lab presents a great opportunity to interest students in chemistry. Get your students involved through questioning, and give them time to think and respond.

THE CHEMISTRY OF BRUISED FRUIT

Laboratory Exercise
-- for the student --

PURPOSE

The purpose of this investigation is to study the effect that oxygen has on peeled or bruised fruit.

MATERIALS

Vitamin C tablets
Fruit juices
Fresh fruit
Any retail "Fruit Fresh"
Test tubes
Stoppers

PROCEDURE 1:

1. Before beginning procedure 2, each lab group should prepare the following six test tubes:

Test Tube	**Color of Fruit**	**Observations**
#1 empty		
#2 empty		
#3 1/2 filled with water		
#4 Full with boiled water		
#5 1/2 filled with vitamin C solution		
#6 1/2 filled with fruit juice		

PROCEDURE 2:

1. Slice an unpeeled apple or pear into six or more pieces.
2. Bruise each piece of fruit by smashing them with your thumb.
3. Quickly place a bruised slice into each test tube. Stopper all test tubes except #1.
4. Wait 25 minutes, then empty the test tubes and make observations on the color of each slice.

PROCEDURE 3: To be done by the teacher.

1. At the beginning of class place several bruised slices of fruit into a solution of store bought fruit fresh.
2. After the 25 minutes, empty the fruit fresh and examine the slices.

SUMMARY QUESTIONS

1. How does the fruit slice in test tube #1 compare with the others?

___

2. How does the fruit slice in the fruit juice compare to that in the vitamin C solution?

___

3. How does mother nature protect her fruit from the oxidative enzymes?

___

4. If you make a fruit salad, how does squirting it with lemon or lime juice help prevent browning?

___

CONCLUSION

Write a brief summary statement on how fruit is changed by bruising and exposure to air.

___

___

___

___

CHEMISTRY: SUNNY-SIDE UP

Laboratory Exercise
-- for the teacher --

PURPOSE

The purpose of this investigation is to study how to coagulate protein.

MATERIALS

Fresh eggs
$AgNO_3$ (.01 M)
$HgCl_2$ (.01 M)
Tannic acid (.1 M)
$Pb(NO_3)_2$ (.1 M)
Ethanol

Pipettes
Test tubes
Beaker
Hot plate

BACKGROUND

In raw egg white, the protein molecules exist separately from each other. These long protein molecules are curled into balls and held together by weak chemical bonds.

Heating breaks the weak bonds which hold the molecules in balls and allows them to unravel. Once unravelled, they can bond to other protein molecules to form large structures which precipitate out.

Electrolytes and alcohols also cause the protein molecules to unravel. Anything that causes the unravelling will also allow the proteins to coagulate.

PRELABORATORY DISCUSSION

1. What are proteins?

Answer -- Large organic molecules, consisting of a chain of amino acids form proteins.

2. What is coagulation?

Answer -- Coagulation is the formation of solids or semisolids by bringing molecules together.

3. How do you cook an egg?

Answer -- You cook an egg by heating it to coagulate the protein molecules.

4. Demonstrate the effect of nitric acid on egg white.

PROCEDURE 1: Egg preparation.

Prepare a solution of albumin by mixing the white of one egg in 100 ml of water.

PROCEDURE 2: Effect of heat.

1. Heat a test tube of albumin in a hot water bath for 5 minutes.

2. Record your observations.

PROCEDURE 3: Effect of alcohol.

1. Mix 5 ml of albumin and 10 ml of ethanol.

2. Record your observations.

PROCEDURE 4: Effect of tannic acid.

1. Mix 5 ml of albumin and 2 ml of tannic acid.

2. Record your observations.
   (Tannic acid can be obtained at drug stores. Cold sore medicines contain 6% tannic acid.)

PROCEDURE 5: Effect of heavy metals.

(CAUTION! Do not allow any of the metal salt solution to come in contact with your skin or eyes.)

1. Add 5 ml of albumin solution to each of three test tubes.

2. Add 20 drops of $AgNO_3$, drop by drop, to the first test tube. Record your observations.

3. Add 20 drops of $HgCl_2$, drop by drop, to the second test tube. Record your observations.

4. Add 20 drops of $Pb(NO_3)_2$, drop by drop, to the third test tube. Record your observations

SUMMARY QUESTIONS

1. Why does a doctor wipe your skin with alcohol before giving you a shot?

Answer -- Alcohol kills the bacteria by coagulating the protein of the bacteria.

2. Children who have accidentally eaten a lead salt may be given egg white. Why?

Answer -- The albumin will coagulate.

CONCLUSION

Write a brief summary on several methods to coagulate an egg.

POSTLABORATORY DISCUSSION

1. Why is heating the safest method for "cooking" an egg?

Answer -- It's the only one that is nontoxic.

2. Why do salts and acids also "cook" proteins?

Answer -- Salts and acids also cause proteins to unravel.

CHEMISTRY: SUNNY-SIDE UP
Laboratory Exercise
-- for the student --

PURPOSE
The purpose of this investigation is to study how to coagulate protein.

MATERIALS
Fresh eggs
$AgNO_3$ (.01 M)
$HgCl_2$ (.01 M)
Tannic acid (.1 M)
$Pb(NO_3)_2$ (.1 M)
Ethanol
Pipettes
Test tubes
Beaker
Hot plate

PROCEDURE 1: Egg preparation.
Prepare a solution of albumin by mixing the white of one egg in 100 ml of water.

PROCEDURE 2: Effect of heat.
1. Heat a test tube of albumin in a hot water bath for 5 minutes.
2. Record your observations.

____

____

PROCEDURE 3: Effect of alcohol.
1. Mix 5 ml of albumin and 10 ml of ethanol.
2. Record your observations.

____

____

PROCEDURE 4: Effect of tannic acid.
1. Mix 5 ml of albumin and 2 ml of tannic acid.
2. Record your observations.

____

____

PROCEDURE 5: Effect of heavy metals.
CAUTION! Do not allow any of the metal salt solution to come in contact with your skin, eyes, or clothing.

1. Add 5 ml of albumin solution to each of three test tubes.

2. Add 20 drops of $AgNO_3$, drop by drop, to the first test tube. Record your observations.

3. Add 20 drops of $HgCl_2$, drop by drop, to the second test tube. Record your observations.

4. Add 20 drops of $Pb(NO_3)_2$, drop by drop, to the third test tube. Record your observations.

SUMMARY QUESTIONS

1. Why does a doctor wipe your skin with alcohol before giving you a shot?

2. Children who have accidentally eaten a lead salt may be given egg white. Why?

CONCLUSION

Write a brief summary on several methods to coagulate an egg.

POSTLABORATORY DISCUSSION

1. Why is heating the safest method for "cooking" an egg?

2. Why do salts and acids also "cook" eggs?

Structure of Matter

Background Information

3

Chemistry, the study of matter, has been under development at least since the Egyptian civilization nearly 5000 years ago. At first it consisted only of a collection of observations and chance discoveries. Gradually, understanding of the principles behind the properties and behavior of matter grew. Even while the developing science was being used for making important materials such as bricks, coloring dyes and metals, thought was being given to why things behave as they do, leading ultimately to atomic theory. In the following, we discuss the properties of matter we can see, that is **macroscopic** matter.

SUBSTANCES

Chemistry deals with the substances which make up our environment. These appear to us as **solids, liquids** and **gases**. In order to understand these substances, it is necessary to study them both at the macroscopic level (i.e., the level which can be seen with the unaided eye) and the microscopic level where features too small to be seen with our eyes alone are considered.

An important property of materials is **homogeneity**. A material is said to be homogeneous if it has uniform properties throughout. Examples of homogeneous substances are shown in Figure 1-1. Heterogeneous materials exhibit different properties depending on what part of the material is being examined. An example of an heterogeneous material is oil and vinegar salad dressing (Fig.1-2) which contains separate droplets of oil and vinegar. It is thus a nonuniform material. An homogeneous material which contains only one chemically distinct substance is known as a pure substance. An example of a pure substance is table salt. Each grain of table salt has the same properties and consists of the same chemical substance, sodium chloride, as every other.

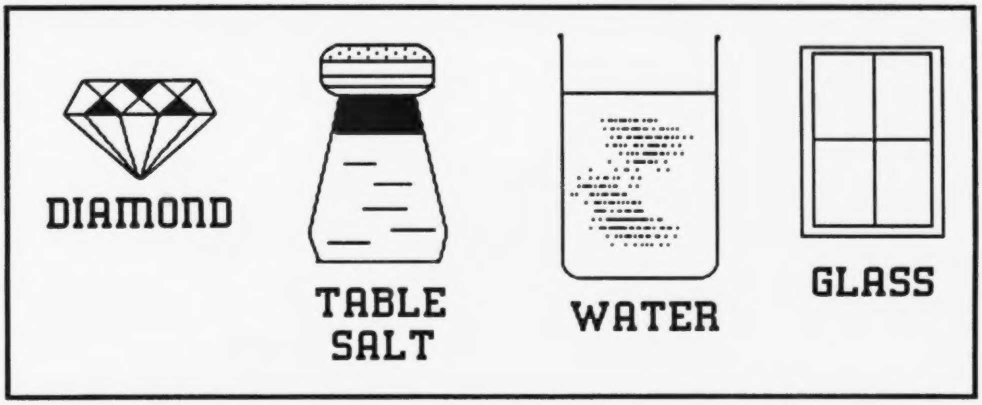


Figure 1-1. Some Homogeneous Substances.

By contrast, ordinary window glass is homogeneous but it is not a pure substance because it contains more than one chemically distinct substance. Pure substances have characteristic properties which are the same for all samples of the substance. A pure solid substance, for example, usually has a characteristic melting point, which is the temperature where the solid phase converts spontaneously to the liquid phase of the substance. Pure ice (the solid phase of water) converts to water at 0° Celsius so we say the melting point of ice is 0°C. This is a characteristic property of pure substances.

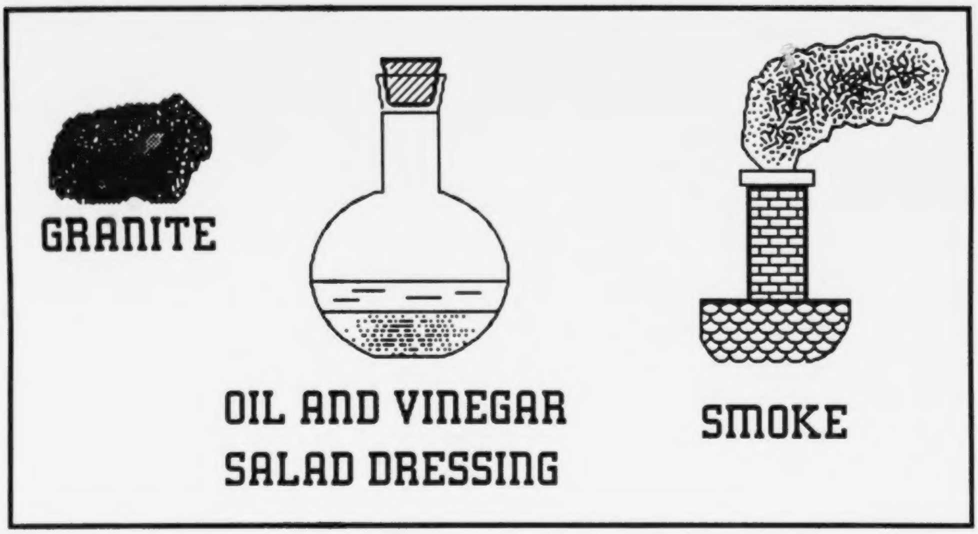

GRANITE
OIL AND VINEGAR SALAD DRESSING
SMOKE

Figure 1-2. Some Heterogeneous Materials.

Note to Teacher: Other homogeneous substances include pure cane sugar, sea water and oxygen gas. Sugar is a pure substance and so is oxygen but sea water is not. Heterogenous substances include milk (even though its said to be "homogenized"), soil and human beings.

Pure substances which are liquids or gases also have characteristic properties. One such is the **boiling point** which is the temperature where a pure liquid under 1.0 atm. pressure converts spontaneously to the gas phase. The boiling point of pure water is 100°C; those of other liquids are shown in Table 1.1.

Table 1.1. Boiling Points of Some Common Liquids.

Liquid	Boiling Pt.°C
Water	100.0
Methyl (wood) alcohol	65.0
Ethyl (grain) alcohol	78.5
Glycerin	290.0

An important characteristic of pure substances is their **constant composition** - that is, all samples of a pure substance contain the same relative amounts of the chemical components. This is a fundamental property of chemical substances. Solutions, on the other hand, are homogeneous but they are not pure substances because their composition is variable.

Iced tea is an example of a solution. One may add no sugar, a little sugar or a great deal of sugar to the tea and still obtain an homogeneous solution upon stirring but the taste tells us that the composition is different in each case. Figure 1-3 illustrates some of the relationships among substances.

Notice that mixtures are listed as heterogeneous substances. Mixtures are physical combinations of substances, that is, the components are physically combined but not chemically combined.

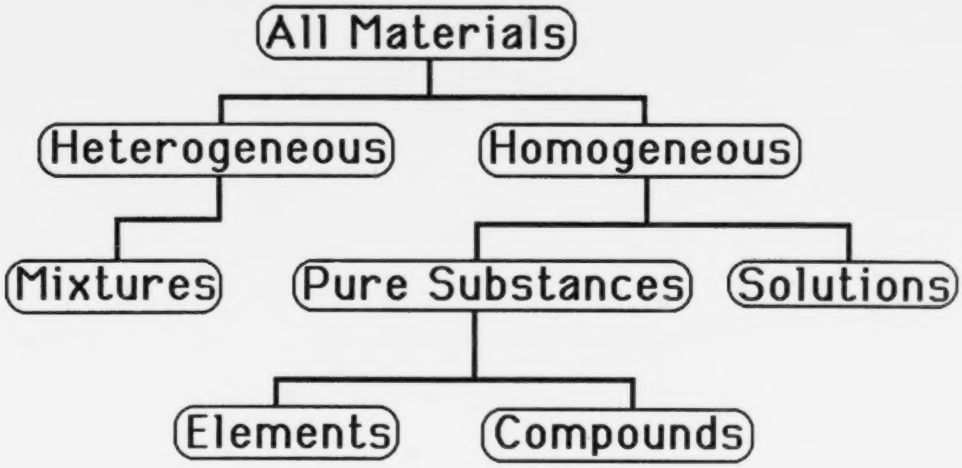

All Materials
Heterogeneous
Homogeneous
Mixtures
Pure Substances
Solutions
Elements
Compounds

Figure 1-3. Chemical Categories of Materials.

To understand the difference, it is useful to consider how mixtures may be separated. Figure 1-4 illustrates filtration, a technique used to separate mixtures of solids and liquids. Imagine a mixture of sand and water. In the Figure, such a mixture is poured into a funnel fitted with filter paper through which the liquid passes leaving the solid trapped in the funnel.

Note to Teacher: The laboratory exercise accompanying this unit involves the use of filtration and evaporation to separate a mixture of sand and a solution of salt in water. Schedule the laboratory exercise at this point.

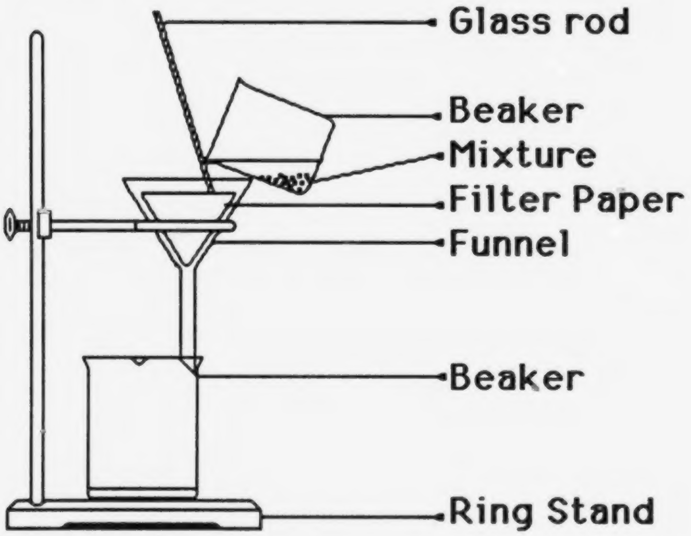

Glass rod
Beaker
Mixture
Filter Paper
Funnel
Beaker
Ring Stand

Figure 1-4. Filtration Apparatus.

One method of separating mixtures of liquids, shown in Figure 1-5, is known as **distillation**. Here we are dealing with liquids which are **miscible**, meaning they dissolve readily in one another, forming an homogeneous solution. The liquids have different boiling points (remember Table 1.1). The solution is placed in the round-bottom flask on the left side of the distillation apparatus in Figure 1-5. The tubular section of the apparatus has a water-cooled jacket to condense vapors which pass through it so it called the condenser. The flask attached to the right end of the condenser is known as the receiver since it receives the pure liquids as they are separated by the apparatus. The flask is heated until the boiling temperature of the lowest-boiling component of the mixture is reached. At that temperature the liquid bubbles and converts spontaneously to the gas phase passing up and into the condenser. There it cools,

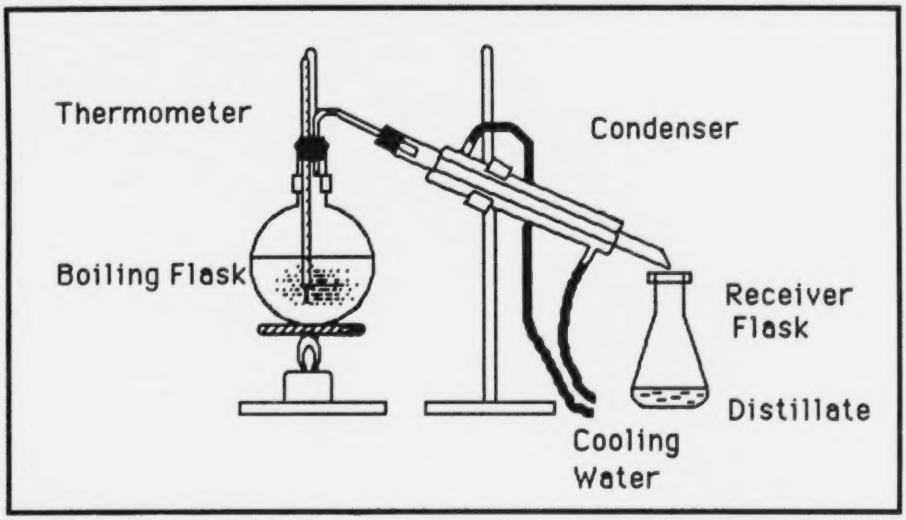


Figure 1-5. Distillation Apparatus.

condenses back to the liquid phase and flows down into the receiver. The purpose of the thermometer in the apparatus is to show when each portion of pure liquid (called a fraction) is distilling off so the receiver can be changed to collect each.

A major use of distillation is in the separation of the components of crude oil affording gasoline, naphtha, kerosene, heating oil, lubricating oil and various waxes . Other important uses include water purification and desalination (removing the salts from sea water).

Solutions of solids in liquids can often be separated by evaporation. Here the solution is simply allowed to stand in a shallow dish until the liquid evaporates, that is, passes into the gas phase without being heated. The vapors of the liquid are lost into the atmosphere but the solid crystallizes in the dish and may be recovered. This method finds use in the recovery of various salts and other substances from sea water and from saline lakes. Large shallow ponds or tanks hold the solution while it evaporates.

ELEMENTS AND COMPOUNDS

Recall from Figure 1-3 that there are only two types of pure substances: elements and compounds. Elements are the one hundred or so fundamental chemical substances which resist all attempts by chemical action to decompose them into simpler substances. Many elements such as aluminum, copper, oxygen and nitrogen are familiar, everyday substances while others such iridium and xenon are rare.

A compound is more complex than an element. Each compound contains two or more elements in chemical combination. There are two important features of compounds:

1. The elements in a compound cannot be separated by physical means such as distillation or filtration. For example, it is possible to separate a mixture of iron powder and sulfur powder by using a magnet to attract the iron leaving the sulfur. It is not possible to separate the iron from the sulfur chemically combined with it in the compound, iron sulfide, by using a magnet or any other physical means.
2. The weight ratio of elements in a certain compound is always the same. This is another way of stating the compounds have constant compositions. The reason for this characteristic lies in the atomic theory which we will examine in the next section.

Thus hydrogen and oxygen are elements and water is a compound composed of the elements hydrogen and oxygen in a fixed weight ratio. We cannot separate the elements in water by any simple physical means. You should recognize from this example that compounds such as water exhibit properties which are very different from the elements which make them up. This difference is the result of what happens in chemical combination.

We have a shorthand method of referring to the elements by their symbols. Some of these are simple, one or two letter representations of the element names such as those shown in Table 1.2.

Table 1.2. Symbols of Some Common Elements.

ELEMENT	SYMBOL	ELEMENT	SYMBOL
Aluminum	Al	Nickel	Ni
Boron	B	Oxygen	O
Carbon	C	Phosphorus	P
Chlorine	Cl	Silicon	Si
Fluorine	F	Titanium	Ti
Hydrogen	H	Uranium	U
Magnesium	Mg	Zinc	Zn

Some of the elements known by the ancients have symbols derived from their Latin names. Some common examples are listed in Table 1.3. A full list of the elements by their symbols is given in the Appendix. While it is not essential for you to learn the symbols for all the elements, their use is so widespread in this text that it will help you to learn the symbols of the more common elements.

Note to Teacher: You may want to ask your students to learn the names and symbols of the first 20 elements since these are emphasized later. It is helpful here to make up flashcards with the element name on one side and the symbol on the other for use in drill.

Table 1.3. Symbols of Some Elements Originally Given Latin Names.

ELEMENT	SYMBOL	ANCIENT NAME
Antimony	Sb	Stibnum
Copper	Cu	Cuprum
Gold	Au	Aurum
Lead	Pb	Plumbum
Mercury	Hg	Hydrargyrum
Potassium	K	Kalium
Silver	Ag	Argentum
Sodium	Na	Natrium
Tin	Sn	Stannum

Compounds are frequently represented in a shorthand way known as their **formula**. Here, the elements which make up the compound are designated by their symbols and subscript numbers are used to show the number of atoms of each element in the formula. If no subscript is shown, a unit amount of that element is understood. The formulas and names of a few common compounds are listed in Table 1.4.

Table 1.4. Formulas of Some Common Compounds.

COMPOUND	FORMULA
Water	H_2O
Sodium Chloride	NaCl
Ammonia	NH_3
Ethanol	C_2H_5OH
Nitrogen Dioxide	NO_2
Calcium Carbonate	$CaCO_3$

MACROSCOPIC STRUCTURE OF MATTER

Paper and Pencil Exercise

--for the teacher--

1. How is homogeneous matter different from heterogeneous matter?

Answer -- The properties of homogeneous matter do not vary anywhere within a sample while those of heterogeneous matter vary depending on what part of the sample is examined.

2. Give two examples each of homogeneous and heterogeneous matter other than those given in the text.

Answer -- Homogeneous: air, rubbing alcohol.
Heterogeneous: Concrete, plywood.

3. Is a solution of salt in water a pure substance? Why or why not?

Answer -- No. It is homogeneous but it contains more than one chemically distinct substance (i.e. salt and water).

4. Define melting point.

Answer -- Melting point is the temperature where a pure solid converts spontaneously into its liquid phase.

5. How could a solution of water and alcohol be separated?

Answer -- Distillation.

6. Give two characteristic features of chemical compounds.

Answer -- Compounds cannot be separated into their components by ordinary physical means. The weight ratio of elements in a certain compound is always the same.

7. Give the formula of the chemical compound called carbon dioxide.

Answer -- CO_2.

MACROSCOPIC STRUCTURE OF MATTER

Paper and Pencil Exercise
--for the student--

1. How is homogeneous matter different from heterogeneous matter?

2. Give two examples each of homogeneous and heterogeneous matter other than those given in the text.

3. Is a solution of salt in water a pure substance? Why or why not?

4. Define melting point.

5. How could a solution of water and alcohol be separated?

6. Give two characteristic features of chemical compounds.

7. Give the formula of the chemical compound called carbon dioxide.

SOLUTIONS AND MIXTURES

Laboratory Exercise

--for the teacher--

PURPOSE

The purpose of this experiment is to use filtration and evaporation to separate the components of a solution and a mixture. If you are not already familiar with the properties of pure substances, solutions and mixtures, review those topics before you begin.

You will need small quantities of salt (sodium chloride), sand (silicon dioxide) and water for the experiment. The quantities of the two solids will need to be measured. If this is not done for you, ask your teacher for instruction on how to use the laboratory balance to measure the needed quantities. The volume of water will also need to be measured with a graduated cylinder the use of which will be demonstrated by your teacher.

Study the instructions carefully before carrying out the experiment. Filtration and evaporation, the new techniques you will learn, play an important role in many science laboratory courses so you will probably use them again in future studies.

MATERIALS

You will need a ring stand with ring, a funnel which fits the ring, a graduated cylinder,two beakers (100-250 mL), and a few circles of filter paper of a size corresponding to the funnel used. Almost any grade of filter paper will work. Also a small to medium evaporating dish or watch glass and a hand magnifying glass or microscope will be needed. There should be a balance capable of weighing to ±0.1g or better available in the laboratory. A small scoop is helpful in transferring the solids.

PRELABORATORY DISCUSSION

The students will prepare a mixture of a water soluble solid (NaCl) and a water insoluble solid (sand). Water is added to this mixture dissolving the salt and forming a suspension (mixture) with the undissolved sand. The qualities of the suspension will depend on how finely divided the sand particles are; using somewhat coarse sand will make the procedure easier.

The suspension of sand in NaCl solution is then filtered by gravity through filter paper using the apparatus in Figure 1-4. Your prelab for the students should include the following items:

1. How to fold the filter paper and wet it to keep it in the funnel.

2. How to use the triple beam or similar balance to measure about three grams of each solid.

3. How to pour the suspension into the funnel without losing any. Here, using a glass rod to direct the flow into the funnel is helpful and a small volume (1-2 mL) of water can be used to wash the residual sand into the funnel. A small plastic wash bottle does wonders for this purpose. Tell the students not to be overly concerned if a little residue remains - this is not meant to be a quantitative experiment!

4. The filtrate solution needs to be allowed to evaporate slowly. This can be accomplished by simply letting it stand until the next week's laboratory period either out on the bench top or in a cabinet somewhere. The students should obtain a crust of nice cubic crystals. Show them how to examine the crystals with a hand magnifier or a microscope.

Finally, emphasize to your students the importance of making complete, accurate observations. This is a vital concept for the students to learn before they go into higher classes in science so include a short critique of their written observations in this experiment along with your usual grading. A useful preparation for this in your prelab is to show the class an ordinary object such as an apple or a book and ask them to write a short paragraph describing it. An acceptable description of an apple would include its color, size, shape, blemishes, presence or absence of stem and any other distinguishing features.

PROCEDURE

Place 2.0 grams of sodium chloride and 2.0 grams of sand in a small beaker (100 mL is about right). Add 10 mL of water to the solid mixture and stir for at least one minute. **Describe the contents of the beaker:**

____

____

Are they better described as a solution or a mixture at this point?

____

Explain your answer.______________________________

____

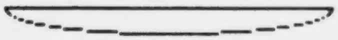
____

Assemble the filtration apparatus shown in Figure 1-4. Be sure there is a beaker under the funnel in which to collect the filtrate, that is the liquid which comes through the filter paper. Ask your teacher to show you how to fold a circle of filter paper so it will fit properly into the funnel. When you are satisfied with the filter paper, place several drops of water on the paper to help keep it down in the funnel. Carefully pour the contents of the beaker into the funnel. Try not to let the level of the solution in the funnel go above the top of the filter paper. (Why not?) Transfer as much of the solid as you can into the funnel.

You may find it helpful to add a small amount of water (not more than 2 mL) to the beaker to help wash the solid into the funnel. Use the glass rod to direct the transfer stream.

Allow as much of the liquid as possible to drain into the lower beaker. Pour the liquid onto a glass evaporating dish or a large watch glass (Fig.1-6) and allow it to sit undisturbed until the next laboratory meeting. (You should label the dish with your initials for identification.)

Evaporating Dish



Watch Glass

Figure 1.6. Apparatus for Evaporating Solutions.

Gently remove the filter paper from the funnel, fold it open and let dry until the next laboratory. Try not to lose any of the solid in the filter paper.

RESULTS AND CONCLUSIONS

Did you find that the filtrate evaporated leaving a solid residue? That would indicate that a solution formed when water was added to the solids. Did you observe a solid on the filter paper? If so, it is evidence that a liquid-solid mixture was separated by filtration.

Examine the particles of any solid residue left from the filtrate using a hand magnifying glass or a small microscope. Describe what you observed and make a sketch at the right.

____

____

____

Compare what you saw with the appearance of particles of sodium chloride and sand. **What can you conclude?**

If a laboratory balance is available, determine the mass of any residue from the filtrate. **Write the mass here.** ___________g

Determine the mass of any solid on the filter paper. **Write the mass here.** ___________g

How does the sum of the masses compare with the starting mass of the mixture of salt and sand?

Which of the solids is more soluble (that is, dissolves to a greater extent) in water?

In Death Valley,California, there are deposits of the mineral borax which were left when a lake dried up thousands of years ago. Borax is a useful material with applications in glass making and cleansers. It occurs in a solid mixture containing various water insoluble minerals. Suppose you needed to obtain quantities of purified borax from the lake bed mixture.
Describe the procedure you would use for separating the borax.

POSTLABORATORY DISCUSSION

The emphasis in your postlab discussion with the students (which should be held during the second week's meeting) should be on using their observations to deduce what happened in the experiment. The observations should be written down as they are made and then studied at the end of the experiment in order to draw the needed conclusions.

First, the students should conclude that it is only NaCl that makes up the solid after the water evaporated from the filtrate. This is determined because the shape of the crystals match those of the NaCl solid they started with. Therefore, an homogeneous phase - a solution in this case - must have formed when NaCl was treated with water. Of course, salt dissolves in water. Sand is absent in the filtrate residue so it must not dissolve in water. Ask your students to suggest an experiment to test this conclusion. (Rerun this experiment leaving out the salt.)

The filter paper is able to separate the liquid phase which passes through it from the solid phase which does not. If the students determine the mass of the filtrate residue and that of the solid left in the filter paper (both must be dry) they should find that substantially all the NaCl comprises the latter and all the sand remains in the former. (The solubility of salt is about 3.5g in 10 mL of cold water.)

The idea that this extraction process is nearly 100% complete (i.e. almost quantitative) leads to the question posed about recovering borax from deposits in Death Valley. In principle, the same process used in this experiment could be used to recover the borax provided that no other soluble minerals are present, and that enough water is used to dissolve all the borax in a given sample. The amount depends on the solubility of borax. Using too little water could leave some borax behind.

SOLUTIONS AND MIXTURES

Laboratory Exercise
--for the student--

PURPOSE

The purpose of this experiment is to use filtration and evaporation to separate the components of a solution and a mixture. If you are not already familiar with the properties of pure substances, solutions and mixtures, review those topics before you begin.

You will need small quantities of salt (sodium chloride), sand (silicon dioxide) and water for the experiment. The quantities of the two solids will need to be measured. If this is not done for you, ask your teacher for instruction on how to use the laboratory balance to measure the needed quantities. The volume of water will also need to be measured with a graduated cylinder the use of which will be demonstrated by your teacher.

Study the instructions carefully before carrying out the experiment. Filtration and evaporation, the new techniques you will learn, play an important role in many science laboratory courses so you will probably use them again in future studies.

MATERIALS

You will need a ring stand with ring, a funnel which fits the ring, a graduated cylinder,two beakers (100-250 mL), and a few circles of filter paper of a size corresponding to the funnel used. Almost any grade of filter paper will work. Also a small to medium evaporating dish or watch glass and a hand magnifying glass or microscope will be needed. There should be a balance capable of weighing to ±0.1g or better available in the laboratory. A small scoop is helpful in transferring the solids.

PROCEDURE

Place 2.0 grams of sodium chloride and 2.0 grams of sand in a small beaker (100 mL is about right). Add 10 mL of water to the solid mixture and stir for at least one minute. **Describe the contents of the beaker:**

____

____

Are they better described as a solution or a mixture at this point?

____

Explain your answer.______________________________________

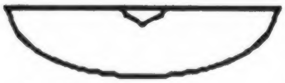
____

____

Assemble the filtration apparatus shown in Figure 1-4. Be sure there is a beaker under the funnel in which to collect the filtrate, that is the liquid which comes through the filter paper. Ask your teacher to show you how to fold a circle of filter paper so it will fit properly into the funnel. When you are satisfied with the filter paper, place several drops of water on the paper to help keep it down in the funnel. Carefully pour the contents of the beaker into the funnel. Try not to let the level of the solution in the funnel go above the top of the filter paper. (Why not?) Transfer as much of the solid as you can into the funnel.

You may find it helpful to add a small amount of water (not more than 2 mL) to the beaker to help wash the solid into the funnel. Use the glass rod to direct the transfer stream.

Allow as much of the liquid as possible to drain into the lower beaker. Pour the liquid onto a glass evaporating dish or a large watch glass (Fig.1-6) and allow it to sit undisturbed until the next laboratory meeting. (You should label the dish with your initials for identification.)



Evaporating Dish

Watch Glass

Figure 1.6. Apparatus for Evaporating Solutions.

Gently remove the filter paper from the funnel, fold it open and let dry until the next laboratory. Try not to lose any of the solid in the filter paper.

RESULTS AND CONCLUSIONS

Did you find that the filtrate evaporated leaving a solid residue? That would indicate that a solution formed when water was added to the solids. Did you observe a solid on the filter paper? If so, it is evidence that a liquid-solid mixture was separated by filtration.

Examine the particles of any solid residue left from the filtrate using a hand magnifying glass or a small microscope. **Describe what you observed and make a sketch at the right.**

____

____

____

____

____

Compare what you saw with the appearance of particles of sodium chloride and sand. **What can you conclude?**

____

____

If a laboratory balance is available, determine the mass of any residue from the filtrate. **Write the mass here.** ____________g

Determine the mass of any solid on the filter paper. **Write the mass here.**

____________g

How does the sum of the masses compare with the starting mass of the mixture of salt and sand?

____

____

Which of the solids is more soluble (that is, dissolves to a greater extent) in water?

____

In Death Valley, California, there are deposits of the mineral borax which were left when a lake dried up thousands of years ago. Borax is a useful material with applications in glass making and cleansers. It occurs in a solid mixture containing various water insoluble minerals. Suppose you needed to obtain quantities of purified borax from the lake bed mixture.
Describe the procedure you would use for separating the borax.

The Periodic Table 4

Background Information

History of the Periodic Table

In the second half of the 19th century efforts were made to uncover patterns among the properties of the known chemical elements. Elements with similar properties were grouped together and trends in their chemical behavior were examined. The task was difficult because a number of elements had not yet been discovered and those which were known were frequently **impure** making their properties uncertain.

The English chemist John Newlands noticed that when the known elements were listed in order of increasing atomic weight, the properties of a given element frequently resembled those of the elements **eight positions forward and backward** in the list. This was known as Newlands's Law of Octaves because of its resemblance to musical octaves. Unfortunately, there were numerous exceptions to the Law of Octaves so it was not accepted by most chemists of the time.

Lothar Meyer, a German chemist, plotted graphs of the elements according to their atomic weights and the volumes occupied by fixed masses. (Mass and volume were among the small number of properties which could be experimentally measured with the crude equipment then available.) His graph showed a series of maxima (peaks) corresponding to the volumes of the elements lithium (**Li**), sodium (**Na**), potassium (**K**), rubidium (**Rb**), and cesium(**Cs**). Meyer showed that **Li, Na** and **K** fitted the Law of Octaves but that the later volume maxima were separated by more than eight elements. Because of the periodic repetition evident on the graph, the series of elements between each maximum were called **periods**. It became clear that patterns existed in the properties of elements and scientists sought a effective way to convey this information.

Credit for the development of the first accepted periodic table of the elements goes to the Russian Dimitri Mendeleev. Like the others, Mendeleev also observed the periodic repetition of physical properties among the elements listed according to atomic weight but it was his arrangement of the elements into a table rather than a graph which first attracted attention to Mendeleev's work, published in 1869. Elements with similar properties were arranged in horizontal rows in Mendeleev's table (Table 2.1). Shown with each is its atomic weight. Notice that several gaps (indicated by **?**) indicating missing elements are present in the table.

Table 2.1. Mendeleev's 1869 Periodic Table*

			Ti=50	Zr=90	?=180
			V=51	Nb=94	Ta=182
			Cr=52	Mo=96	W=186
			Mn=55	Rh=104.4	Pt=197.4
			Fe=56	Ru=104.4	Ir=198
			Ni=Co=59	Pl=106.6	Os=199
H=1			Cu=63.4	Ag=108	Hg=200
	Be=9.4	Mg=24	Zn=65.2	Cd=112	
	B=11	Al=27.4	?=68	Ur=116	Au=197?
	C=12	Si=28	?=70	Sn=118	
	N=14	P=31	As=75	Sb=122	Bi=210
	O=16	S=32	Se=79.4	Te=128?	
	F=19	Cl=35.5	Br=80	I=127	
Li=7	Na=23	K=39	Rb=85.4	Cs=138	Tl=204
		Ca=40	Sr=87.6	Ba=137	Pb=207
		?=45	Ce=92		
		?Er=56	La=94		
		?Yt=60	Di=95		
		?In=75.6	Th=118?		

---

*Source: I. Asimov,"A Short History of Chemistry", Doubleday, 1965.

Instead of accepting the gaps in the table as imperfections, Mendeleev boldly predicted that new elements would be discovered which would fill the gaps! Remember that the ability to make correct predictions is a powerful tool for the scientist. He even suggested what some of the properties of the missing elements would be. This was done by **interpolating** the properties of the other elements surrounding the missing element in the table. By interpolation, we mean he used the **trends** in properties such as melting point and density to get an estimate of the values of these properties for the missing element. For example, listed in Table 2.2 are some of the properties he predicted for the missing element with atomic weight between 68 and 75 (dubbed **eka-silicon** by Mendeleev and later named **germanium**, in honor of the home country of its discoverer Clemens Winkler).

Note to the Teacher: A short example of how interpolation works is helpful at this point. These data may be used. Density of SiO_2 = 2.6 g/cm^3. Density of SnO_2 = 6.8 g/cm^3. This gives an interpolated density of GeO_2 assuming a linear trend of (2.6 + 6.8)/2=4.7 g/cm^3.

Table 2.2. Predicted and Actual Properties of a Missing Element

Property	**Predicted (1871)** **eka-silicon**	**Found (1886)** **germanium**
Atomic Weight	72	72.3
Specific gravity	5.5	5.46
Color	dark gray	light gray
Specific gravity MO_2	4.7	4.70

It was the unprecedented accuracy of these predictions which convinced the scientific world of the validity of Mendeleev's periodic table.

The modern periodic table (Fig. 2-1) has evolved into a somewhat different arrangement of elements than the earlier tables.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104	105	106												
				58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
				90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lw

Figure 2-1. A Modern Periodic Table.

The elements are now arranged from left to right in order of increasing **atomic number** instead of atomic weight. Elements in the same **vertical** column are called a **group** signifying that they resemble each other in their properties. **Horizontal** rows are still known as **periods**.

Note to the Teacher: Please note that the method of labeling groups in the periodic table with Roman numerals followed by the letters A or B has been replaced with the simple scheme recommended by the American Chemical Society whereby the groups are simply numbered increasing from left to right.

Each entry in the table consists of the symbol of the element, its atomic number above the symbol and in some versions, its average atomic weight below the symbol. Figure 2-2 shows a typical entry.

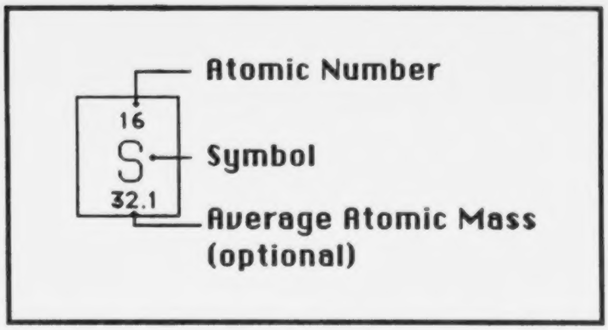

Atomic Number
16
S
32.1
Symbol
Average Atomic Mass (optional)

Figure 2-2. An Entry from the Periodic Table.

Note to the Teacher: The pencil and paper exercise on the periodic table (please see pages 4-14 through 4-18) should be scheduled at this point. It illustrates trends in properties of elements.

Scientists have discovered that the reason for the patterns seen in the properties of the elements in the periodic table is the orderly change in the **valence electronic configuration** of the elements. This refers to the number of electrons in the outermost shell and what orbitals they occupy. Beginning at the extreme left side of the table, the Group 1 elements (**Li-Fr**) have only one electron occupying an s orbital in the outermost or **valence shell**. Hydrogen is listed with the Group 1 elements (and also sometimes with the Group 17 elements) because of its unique chemical properties resemble those of both groups in some ways.

Figure 2-3 shows the format of the periodic table based on the valence

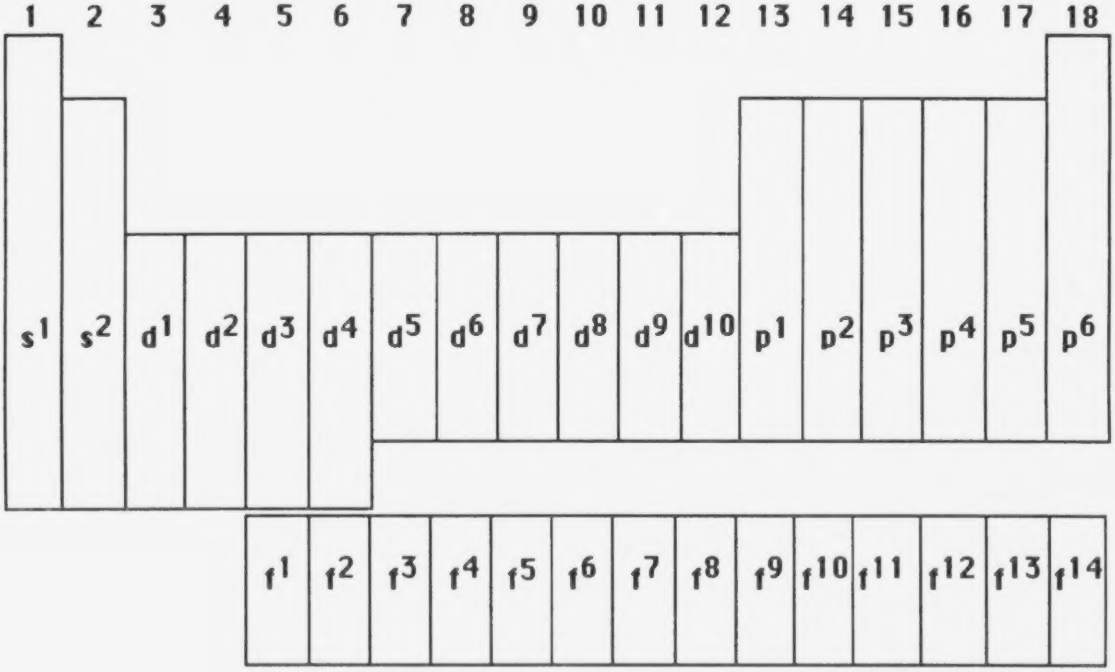

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
s1 s2 d1 d2 d3 d4 d5 d6 d7 d8 d9 d10 p1 p2 p3 p4 p5 p6
f1 f2 f3 f4 f5 f6 f7 f8 f9 f10 f11 f12 f13 f14

Figure 2-3. Valence Electronic Configurations for Each Group.

configuration of each group. The outermost electron is shown for each group. In some cases the element groups are given trivial names - thus Group **1** is known as the **alkali metals.** The Group 2 elements (**Be-Ra**) have two s electrons in the valence shell and are known as the **alkaline earths.**

Groups 13-18 contain elements in which one to six electrons are present in the outermost shell (valence) p orbitals. For example, the element boron (Z=5) occupying Group **13** has three electrons in its valence shell $2s^2 2p^1$) while the element sulfur (Z=16) occupying Group 16 has six electrons arranged as $3s^2 3p^4$. Common names given to groups **17** and **18** are **halogens** and **noble gases.**

Inspection of Figure 2-4 shows that **Main Group** (1,2, 13-18) elements have valence electronic configurations involving s or s and p orbitals.

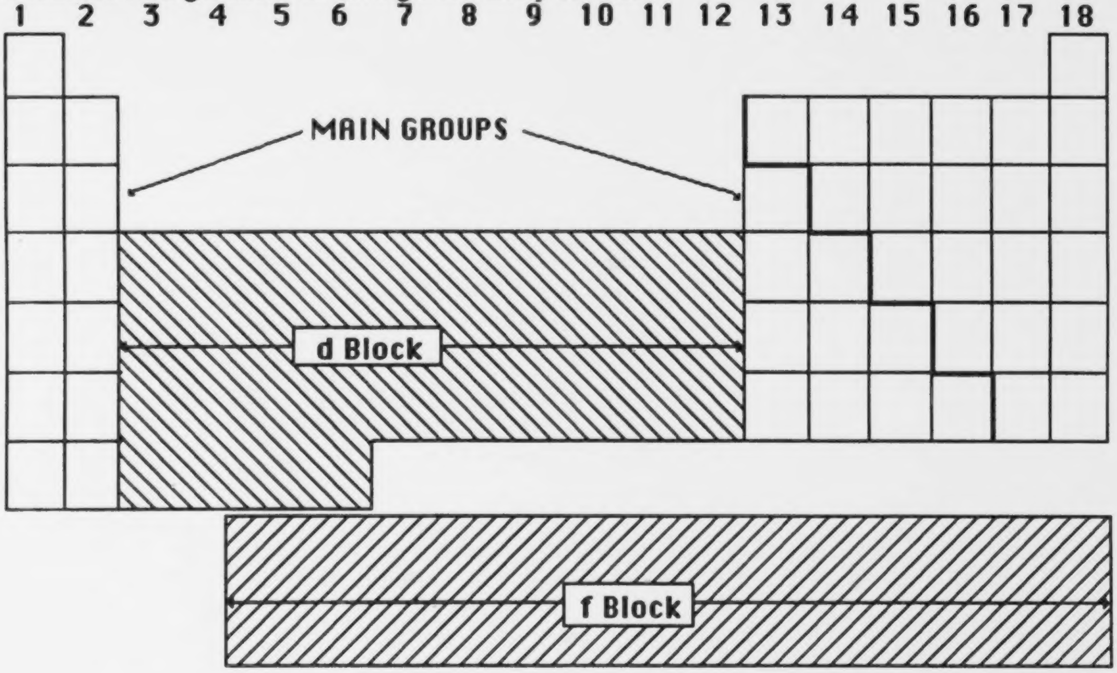


Figure 2-4. Main Group, d and f Blocks within the Periodic Table.

You should be able to write the full electronic configuration of the first 20 atoms by remembering the order of the **subshells** according to their position in the periodic table. In order to determine the electronic configuration, one may use the periodic table by noting which orbitals are being filled in the various blocks of the table as shown in Figure 2-3. The elements in the Main Groups (1,2,13-18) have electrons being added to s or p subshells in the **s** and **p blocks,** respectively. The elements in the Groups 3-12 are called **d-block** elements to indicate that d subshells are being filled. The last group of elements in the **f-block** at the bottom of the table have electrons being added to f subshells.

Electrons are added one by one to the valence shell of atoms at each group moving from left to right across a period in the table (Figure 2-3). This scheme makes it simple to determine the valence configuration of Main Group elements. As an example, consider calcium, **Ca**, (Z=20). The element lies in the fourth row down in the table and is the 2nd element in the s-block. The electrons which are present can be determined by starting at the left upper corner of the table and moving to the element in question following increasing atomic number and taking a full s, p, d or f-block at a time.

For Ca: $1s^2 + 2s^2 + 2p^6 + 3s^2 + 3p^6 + 4s^2$ **Valence shell = $4s^2$**

Notice that the valence configuration gives number of electrons in the outermost shell, that is the subshells with the largest value of the quantum number n. The total number of electrons (sum of the superscripts) must equal 20. The valence electrons are those corresponding to the lowest period, the fourth in the case of calcium.

The Formation of Ions

An **ion** is formed when an atom gaines or loses one or more electrons. Since electrons bear negative charges, losing an electron from an atom leaves a **positive ion** and gaining an electron forms a **negative ion**.

The term **cation** is used to indicate an ion with one or more positive charges. Atoms from groups on the left side of the periodic table share a readiness to form cations through loss of electrons. For example, **Na**, element 11, forms the sodium cation, **Na^{1+}** in many of its compounds.

An important principle in the formation of ions is that a special stability is associated with atoms and ions which have **no vacancies** in their valence electronic configurations. Since the horizontal rows in the periodic table represent filling of the valence shells of the elements, it follows that it is the elements on the extreme right side of the table (Group **18**) which have filled valence shells. For instance, neon (Z=10), has a valence configuration of $2s^2 2p^6$; there are no vacancies since s subshells have a capacity of 2 electrons and p subshells have a capacity of 6 electrons. All the Group **18** elements have an s^2p^6 outer configuration and they are described as having a complete **octet** referring to the eight s and p electrons.

The special electronic stability of the Group **18** elements is reflected in a very low chemical reactivity of the elements - **He**, **Ne** and **Ar** form no known compounds and the heavier members, **Kr**, **Xe** and **Rn**, do so only under extreme conditions. It follows that elements near Group **18** in the table should lose or gain electrons forming ions with **complete octets**.

Consider the Group **1** elements. Each has just one electron beyond a filled shell as shown in Figure 2-5. The chemical behavior of these elements is dominated by their loss of electrons forming stable cations having electronic configurations the same as the Group **18** element preceding them in the table. (Remember to follow the order of increasing atomic number.)

This chemical behavior is recognized by assigning **oxidation numbers** of **+1** and **+2** to the elements in Groups **1** and **2**. The positive signs of these oxidation numbers mean that the elements usually lose electrons when forming compounds with other elements. The numbers themselves indicate how many electrons are given up by each atom of the element.

Positive oxidation numbers are associated with elements have 4 or less electrons in their valence shells.

Group 1		Valence	Group 2		Valence
Lithium	Li	$2s^1$	Beryllium	Be	$2s^2$
Sodium	Na	$3s^1$	Magnesium	Mg	$3s^2$
Potassium	K	$4s^1$	Calcium	Ca	$4s^2$
Rubidium	Rb	$5s^1$	Strontium	Sr	$5s^2$
Cesium	Cs	$6s^1$	Barium	Ba	$6s^2$
Francium	Fr	$7s^1$	Radium	Ra	$7s^2$

$M = M^{1+} + 1e^-$

$M = M^{2+} + 2e^-$

Figure 2-5. Groups **1** and **2** from the Periodic Table. (**M** is a general symbol for a metallic element.)

The alkaline earth metals have two electrons in their valence shells. Therefore, their atoms must lose two electrons in order to achieve a configuration with a complete octet. Figure 2-5 shows the elements from Group **2**, their valence configurations and the formation of a cation with two positive charges by a representative of the group.

It is important to understand that some energy must be expended to remove an electron from **any** atom. Because ions with very stable electronic configurations such as Na^+ and Mg^{2+} are formed, electrons can be removed from the atoms of Group**1** and **2** elements with less energy than from most other elements. Higher groups require so much energy to remove the three or more electrons necessary to reach a filled-shell ion that their ions are not very stable.

Atoms with **nearly filled** valence shells may act as electron acceptors forming **anions** (negative ions) with filled valence shells. Two instances where this produces very stable anions are Groups **16** and **17**. Elements in the former group exhibit s^2p^4 configurations while those in the latter have s^2p^5 configurations so the groups are 1 electron and 2 electrons short of filled shells (s^2p^6). As illustrated in Figure 2-6, fluorine adds one electron forming F^-, the fluoride ion, which has the same number of electrons as the Group **18** element, **Ne**. Similarly, oxygen adds two electrons producing O^{2-}, the oxide ion. Neon atom, fluoride ion and oxide ion all have the same number of electrons (10).

The oxidation numbers of group **16** and **17** elements are **-2** and **-1**, respectively, representing the number of electrons they gain in reaching filled shells. The negative sign indicates that the atoms **gain** electrons.

Group 16		Valence	Group 17		Valence
Oxygen	O	$2s^2 2p^4$	Fluorine	F	$2s^2 2p^5$
Sulfur	S	$3s^2 3p^4$	Chlorine	Cl	$3s^2 3p^5$
Selenium	Se	$4s^2 4p^4$	Bromine	Br	$4s^2 4p^5$
Telurium	Te	$5s^2 5p^4$	Iodine	I	$5s^2 5p^5$
Polonium	Po	$6s^2 6p^4$	Astatine	At	$6s^2 6p^5$

$$E + 2e^- = E^{2-} \qquad E + 1e^- = E^-$$

Figure 2-6. Groups **16** and **17** from the Periodic Table. (**E** is a general symbol for a nonmetallic element.)

The oxidation numbers of the Main Group elements are listed below:

Group No.:	**1** IA	**2** IIA	**13** IIIA	**14** IVA	**15** VA	**16** VIA	**17** VIIA	**18** VIIIA
Oxid. No. :	+1	+2	+3	+4,-4	-3	-2	-1	0

Notice that the elements in Group **14** are given oxidation numbers of +4 and -4. Having 4 valence electrons, an exactly half-filled valence shell, the elements can form compounds by either gaining 4 electrons or losing four electrons so two oxidation numbers are needed. It is important to realize, however, that Group **14** elements form almost no ionic compounds because of the large amounts of energy needed to actually gain or lose so many electrons. Instead they **share** electrons leading to **covalent** bonding.

Note to the Teacher The laboratory exercise can scheduled at this point. It requires the students to arrange cards containing selected properties of some main group elements into their proper positions in the periodic table. The students will have to be familiar with trends in periodic properties of elements, the positions of metals and nonmetals in the table and the variation of oxidation number between element groups within the table to successfully complete the exercise.

ELECTRON DOT PICTURES

A useful method for showing the valence electronic configuration of an atom is through **electron dot pictures**, which, as the name implies, have dots surrounding the symbol of an atom to represent its valence electrons. Electron dot diagrams are used extensively in describing chemical bonding and structure so it is helpful to learn to construct such diagrams at this point. Only Main Group elements (i.e. those from Groups **1,2 and 13-18** in the periodic table) will be considered.

Figure 2-7 shows the electron dot diagrams and valence electronic configurations of the first 10 elements. Notice that hydrogen's single electron is represented as a single dot. Helium has two electrons and these are represented as a pair of dots because the valence shell of He consists solely of the 1s orbital so the two electrons must be paired ($1s^2$) as shown by the dots. The dot diagrams for elements from Groups **1**and **2** consist of a single dot and a pair of dots representing the s^1 and s^2 configurations as shown for lithium and beryllium in the Figure.

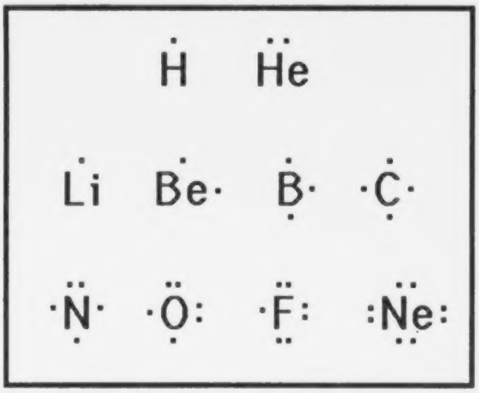


Figure 2-7. Electron Dot Diagrams for the First 10 Elements.

In order to construct a dot diagram for an element from Groups **13** to **18**, two steps are required:

1. Count the number of electrons in s and p orbitals in the valence shell.

2. Place one dot around the symbol of the atom for each electron up to 4 then form pairs of dots for the remaining electrons up to the maximum of 8.

For example, consider nitrogen which has 5 valence electrons. The first 4 electrons are placed singly around the symbol and the last electron forms a pair with one of the single electrons. The dot diagram clearly shows us that nitrogen atom has three electrons which are **unpaired** and two which are **paired**. This information can help determine the number of **chemical bonds** an atom may form.

Some of the heavier Main Group elements have valences which can be expanded to contain 10 or even 12 electrons. This behavior can also be described using electron dot pictures but we will not consider them her

IONIC COMPOUNDS

We have seen that elements from the left side of the periodic table can lose electrons to form stable cations and those from the right (excluding Group **18**) may gain electrons to form stable anions. Figure 2-8 illustrates an atom of cesium losing its valence electron to form Cs^+.

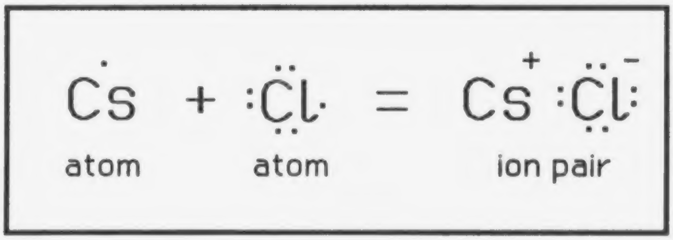


Figure 2-8. The Formation of an Ion Pair Between Group **1** and **17** Atoms

An atom of chlorine accepts the electron filling the single vacancy in its valence shell and forming Cl^-. Due to the attraction of their charges, the two ions come together forming an **ion pair**. This process is oversimplified in that it shows these atoms and ions as **isolated** from others but it serves to illustrate the basic steps in the formation of ionic compounds.

The formation of stable ionic compounds takes place mainly between atoms from Groups **1** and **2** and atoms from Groups **16** and **17**. For example, when cesium and chlorine are actually combined, the ionic compound **cesium chloride** is produced. Instead of just ion pairs, its structure consists of a three-dimensional arrangement of Cs^+ ions and Cl^- ions in which each positive ion is surrounded by 8 negative ions at the corners of a cube as shown in Figure 2-9. In the same way each negative ion is surrounded by a cube of 8 positive ions. This arrangement gives the structure great stability because of the strong electrostatic attractions. **Sodium chloride** (table salt) has a related structure and several other similar structures are known for other ionic compounds.

Note to the teacher: The structure is most easily understood by viewing a three dimensional model of the structure. Such can be made from styrofoam balls and toothpicks. Its construction can be a special project for interested students.

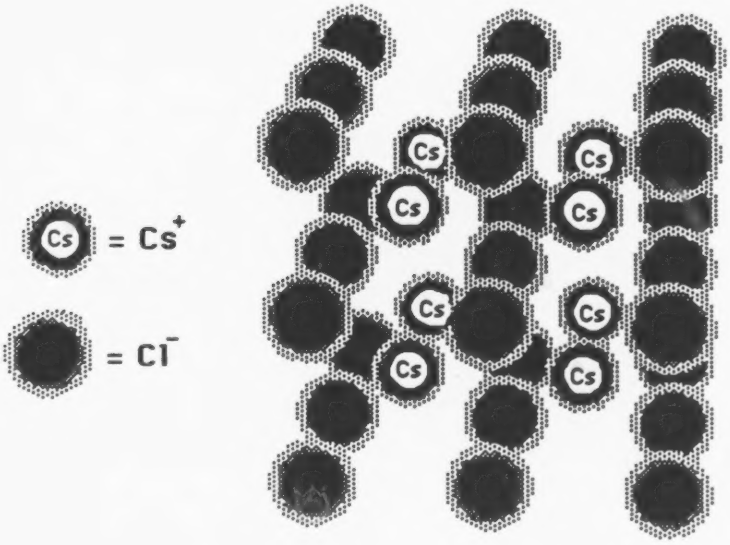


Figure 2-9. Segment of the Solid State Structure of Cesium Chloride.

The elements from Group **2** give ionic compounds when reacted with those of Groups **16** and **17** as illustrated in the following equations.

$$\mathbf{Ca + 2F} \;=\; \mathbf{Ca^{2+}} + 2\mathrm{F}^- \text{ or simply } \mathbf{CaF_2}$$
$$\mathbf{Ca + O} \;=\; \mathbf{Ca^{2+}} + \mathrm{O}^{2-} \text{ or } \mathbf{CaO}$$

Calcium atoms must lose two electrons to reach an octet configuration so two fluorine atoms, each of which can accept one electron, combine with calcium to form **calcium fluoride**, an ionic compound composed of $\mathbf{Ca^{2+}}$ and $\mathbf{F}^-$ ions. In the case of oxygen, the Group **16** element requires two electrons to reach an octet configuration, so one **Ca** and one **O** combine to form **calcium oxide** as shown above.

Ionic compounds have melting points well above room temperature reflecting the strong electrostatic forces present in ionic bonding. The presence of ions in the structures has been verified by melting compounds such as sodium chloride and showing that the melt conducts **electric current**. Only through the movement of ions in the liquid can current be conducted - solid ionic compounds do not conduct because the ions can't move.

The ionic compounds described so far are **binary** compounds, that is they consist of just two elements. With very few exceptions such binary ionic compounds consist of a **metal** and a **nonmetal**. Figure 2-10 shows that metals occupy the areas of the periodic table to the left of and below the zig-zag line running from boron (Z=5) down to polonium (Z=84). Nonmetals occupy the remaining section of the table to the right of the line. Elements adjacent to the line are often called **semimetals** to indicate that they have some properties of metals and some of nonmetals.

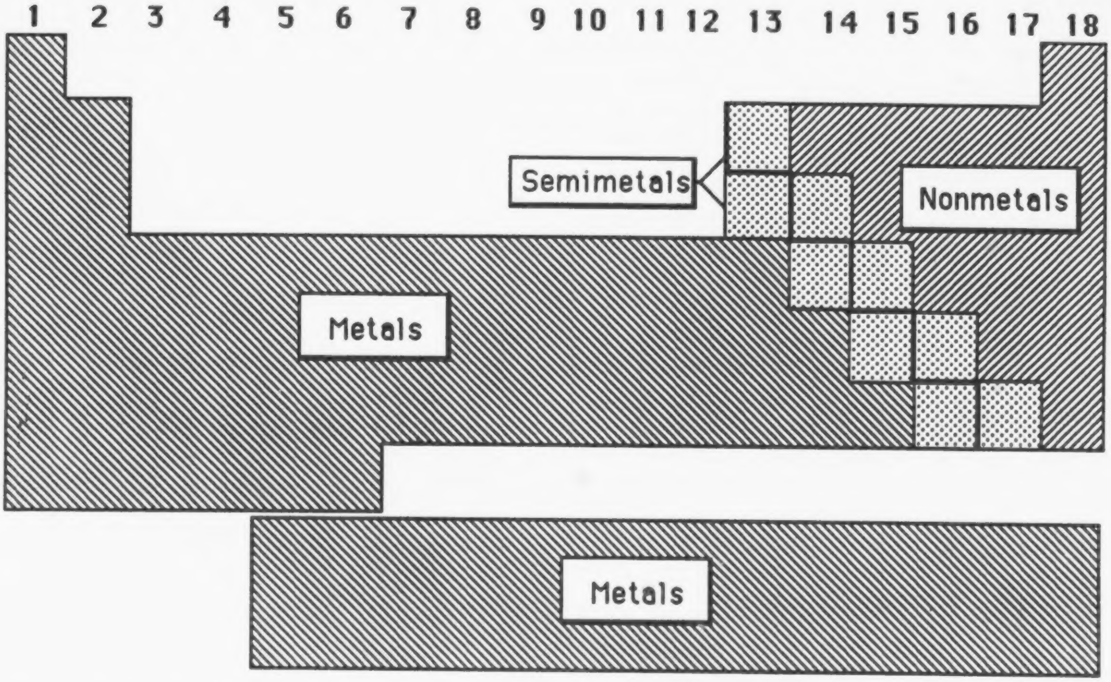


Figure 2-10. Distribution of Metals, Nonmetals and Semimetals in the Periodic Table.

Names of Ionic Compounds

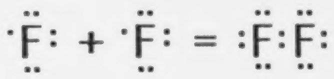
In assigning names to binary ionic compounds, the metal (positive ion) is named first followed by the name of the nonmetal (negative ion) modified with an "ide" ending.

Examples: **LiBr** lithium bromide
CaF_2 calcium fluoride

Notice that it is not necessary in these simple compounds to include an indication of the number of fluoride ions in calcium fluoride because it is understood from the oxidation number of calcium that there must be two fluorides. It is therefore important to become familiar with the oxidation numbers of the elements.

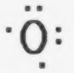
Covalent Bonding

Atoms can achieve a filled-shell electronic configuration by **sharing** electrons as well as by losing or gaining electrons. Consider two fluorine atoms shown below.

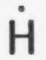


Each fluorine has one electron which is unpaired. Bringing the atoms together such that the single electrons can form a pair shared between the two atoms produces what is known as a **covalent bond** (a shared pair of electrons) between the fluorines. The bond stabilizes the two atoms as a **molecule** of fluorine. Remember that ionic bonds result when electrons are transferred between atoms in contrast to being shared as in covalent bonds.

Using the octet rule and the periodic table, we can predict the number of atoms which will combine to form a stable molecule. With few exceptions, each atom in a molecule will share enough electrons with other atoms to reach a filled shell configuration. Usually this means each atom has a share in a total of eight electrons. Exceptions are hydrogen (for which a filled shell is two electrons), d-block elements and some of the heavy Main Group elements, which can accommodate 10, 12 or more electrons. Shown below are atoms of oxygen and hydrogen with their valence electrons.

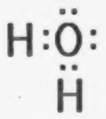


Six electrons-needs to share two more for a filled shell.



One electron-needs to share one more for a filled shell.

In order to form a stable molecule, hydrogen needs to form a pair of electrons with oxygen and the oxygen needs to form two pairs with hydrogens. Therefore, two hydrogens are required for each oxygen and the formula for the molecule must be H_2O.



All three atoms have filled shells by sharing.

Water molecule

In order for two atoms to share electrons instead of transferring them as was seen in ionic compounds, the atoms must be members of Groups which are **close neighbors** in the periodic table. Some examples where the formation of covalent bonds by sharing electron pairs occurs are **H** and **Cl**, **O** and **F**, **F** and **Cl**, **C** and **Cl**, and **H** and **N**. Obviously identical atoms or atoms from the same Group will share electrons most evenly. Examples are $\mathbf{H_2}$, $\mathbf{F_2}$, $\mathbf{Na_2}$ and **ClF**.

As the Group separation of the combining atoms increases, the electron is shared more and more unevenly. For example, $\mathbf{F_2O}$ has nearly equal sharing, $\mathbf{NF_3}$ and $\mathbf{CF_4}$ have the electron pairs in the covalent bonds displaced towards fluorine and $\mathbf{AlF_3}$ is nearly an ionic compound with the electron pairs displaced strongly towards the fluorine.

THE PERIODIC TABLE AND FORMULAS

Paper and Pencil Exercise

--for the teacher--

1. From memory make a sketch of the four blocks of the periodic table.

2. Write the valence electronic configurations for **C**, **S**, **Ne** and **Na**.
Answer -- C $2s^22p^2$; S $3s^23p^4$; Ne $2s^22p^6$; Na $3s^1$.

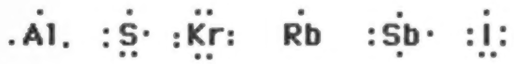
3. The formation of the Group **1** cations is shown in Figure 2-5.

a. What is the valence electronic configuration of **Na$^+$**?
Answer -- $2s^22p^6$

b. What atom has the same electronic configuration as **Na$^+$**?
Answer -- **Ne**

4. Nitrogen (Z=5) forms an anion. What is the formula for the anion and how many electrons are required to produce it?
Answer -- N is three electrons short of a filled shell so the stable anion is N^{3-}. Three electrons are required to produce the ion.

5. Draw the electron dot diagrams representing the valence electrons for the following elements: **Al**, **S**, **Kr**, **Rb**, **Sb**, and **I**.
Answer --



$$.\overset{\cdot}{\mathrm{Al}}. \quad :\underset{\cdot\cdot}{\overset{\cdot}{\mathrm{S}}}\cdot \quad :\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{Kr}}}: \quad \overset{\cdot}{\mathrm{Rb}} \quad :\underset{\cdot}{\overset{\cdot}{\mathrm{Sb}}}\cdot \quad :\underset{\cdot\cdot}{\overset{\cdot}{\mathrm{I}}}:$$

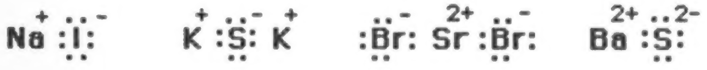
6a. Write the formulas for the ionic compounds which will form from each of these pairs of elements.

Sodium and iodine　Strontium and bromine
Potassium and sulfur　Barium and sulfur

Example: Magnesium and chlorine form **$MgCl_2$**.

Answer -- **NaI**, **K_2S**, **$SrBr_2$**, **BaS**.

6b. Write formulas showing the electron dot structures for all the ions in the compounds from part 6a.
Answer --



$$\mathrm{Na}^{+} :\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{I}}}:^{-} \qquad \mathrm{K}^{+} :\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{S}}}:^{-}\ \mathrm{K}^{+} \qquad :\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{Br}}}:^{-}\ \mathrm{Sr}^{2+} :\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{Br}}}:^{-} \qquad \mathrm{Ba}^{2+} :\underset{\cdot\cdot}{\overset{\cdot\cdot}{\mathrm{S}}}:^{2-}$$

7a. Write the formulas for radium sulfide, beryllium iodide and lithium oxide.
Answer -- **RaS**, **BeI_2**, **Li_2O**.

b. Write names for **BaS**, **$SrBr_2$**, **NaF** and **K_2O**.
Answer -- Barium sulfide, strontium bromide, sodium fluoride and potassium oxide.

8. Predict the formulas for the stable molecules between each of the following pairs of elements.

Hydrogen and chlorine	Fluorine and chlorine	Oxygen and fluorine
Hydrogen and nitrogen	Hydrogen and carbon	Carbon and fluorine

Answer -- **HCl, ClF, F_2O, NH_3, CH_4, CF_4**

9. Identify each of the atoms from question 5 as metals, nonmetals, or semimetals.
Answer -- **Al**, semimetal; **S**, nonmetal; **Kr**, nonmetal; **Rb**, metal; **Sb**, nonmetal; **I**, nonmetal.

10. Identify each of the following compounds as ionic or covalent:
calcium bromide nitrogen trifluoride lithium oxide sulfur dioxide
Answer -- **$CaBr_2$**, ionic; **NF_3**, covalent; **Li_2O**, ionic; **SO_2**, covalent.

THE PERIODIC TABLE AND FORMULAS

Paper and Pencil Exercise
--for the student--

1. From memory make a sketch of the four blocks of the periodic table.

2. Write the valence electronic configurations for **C**, **S**, **Ne** and **Na**.

3. The formation of the Group 1 cations is shown in Figure 2-5.

   a. What is the valence electronic configuration of $\mathbf{Na^+}$?

   b. What atom has the same electronic configuration as $\mathbf{Na^+}$?

4. Nitrogen (Z=5) forms an anion. What is the formula for the anion and how many electrons are required to produce it?

5. Draw the electron dot diagrams representing the valence electrons for the following elements:
   Al, **S**, **Kr**, **Rb**, **Sb**, and **I**.

6a. Write the formulas for the ionic compounds which will form from each of these pairs of elements.

Sodium and iodine   Strontium and bromine
Potassium and sulfur   Barium and sulfur

Example: Magnesium and chlorine form $\mathbf{MgCl_2}$.

6b. Write formulas showing the electron dot structures for all the ions in the compounds from part 6a.

7a. Write the formulas for radium sulfide, beryllium iodide and lithium oxide.

b. Write names for **BaS**, **$SrBr_2$**, **NaF** and **K_2O**.

8. Predict the formulas for the stable molecules between each of the following pairs of elements.

Hydrogen and chlorine
Hydrogen and nitrogen
Fluorine and chlorine
Hydrogen and carbon
Oxygen and fluorine
Carbon and fluorine

9. Identify each of the atoms from question 5 as metals, nonmetals, or semimetals.

10. Identify each of the following compounds as ionic or covalent:
calcium bromide nitrogen trifluoride lithium oxide sulfur dioxide

PERIODIC TRENDS IN THE PROPERTIES OF THE ELEMENTS

Paper and Pencil Exercise

--for the teacher--

Introduction

The Periodic Law states that the properties of elements are periodic functions of the atomic number of the element. Here the words "are functions of" mean "are determined by". The variation of properties is in some way determined by the variation in atomic number of the elements.

The recognition of periodic trends or patterns in the properties of elements was instrumental in the development of the periodic table. Later it was related to the electronic configuration of atoms. These periodic trends are easily seen if the values of the properties are plotted with the atomic numbers of the elements on a graph.

Purpose

The purpose of this exercise is to construct plots of some elemental properties to demonstrate the Periodic Law.

Notes to the Teacher

This exercise is intended to give your students experience in constructing plots and to illustrate for them the repeating patterns shown by the properties of elements. Constructing and examining such plots aided Newlands, Mendeleev and others in developing the first periodic tables. Each repeating trend corresponds to a period in the table. Trends have different lengths as do the horizontal periods in the periodic table. Maxima and minima in the plots correspond to elements in the same vertical groups in the table.

As you can see from **Figure 1**, trends are not always smooth - there are points which fall above and below the smooth trend line - so the students should look for broad trends. The choice of density as a parameter to plot was made to illustrate the mechanics of plotting rather than periodic variation of properties. Because density is more sensitive to structural differences than most physical properties, its plot doesn't show clean-cut trends as well as some.

Assign each student one of the properties listed in the Table to plot. The best types of graph paper to use are cm/mm or inches/0.1inch but almost any type with at least 55 divisions on each axis will suffice.

Procedure

Table 1 contains a selection of elements along with values of some of their properties. Your teacher will assign you one or two properties to plot. Set up your graph as follows:

1. On the horizontal axis place the atomic numbers for the elements in the table. The figure below illustrates how the assignment of values should be done. The smallest division on the graph paper should correspond to one unit of atomic number. Label the axis and place numbers every 5 or 10 units on the axis.

2. On the vertical axis plot the values of your assigned property. As shown in the figure, the maximum value should fall near the top of the graph paper and the minimum value near the bottom. Pay close attention to the correct assignment of the scale units. Label the axis.

3. Finally, make a dot on the graph for each set of values (atomic number, property) at the appropriate position according to the axes scales. Connect each dot to its nearest neighbor with a straight line segment. Notice that data are missing in some cases. When that happens, draw a dotted line on the graph.

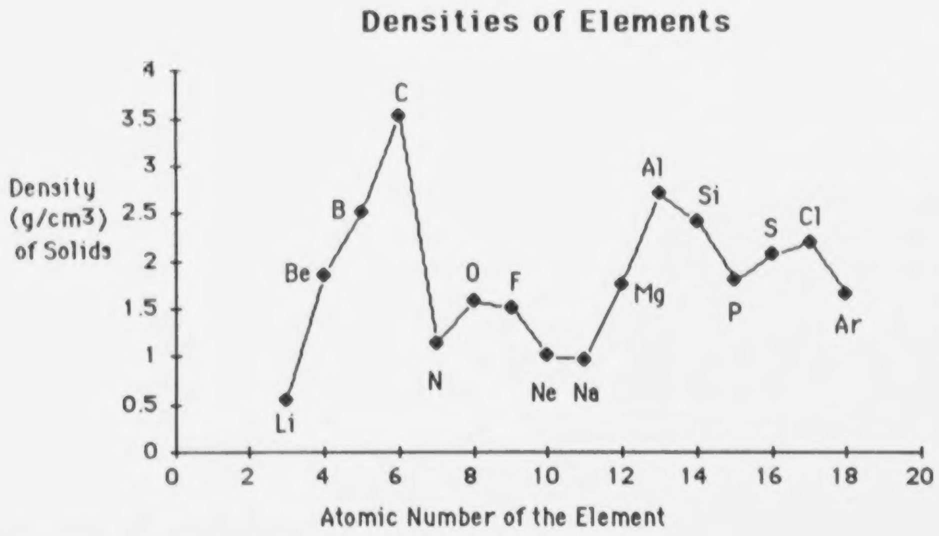


Figure 1. The Densities of Some Elements.

Analysis

Inspect the regions of your graph(s) between atomic numbers 3 through 10 and 10 through 18. How do they compare? Do the same for regions 19 through 36 and 37 through 54. How smooth are the variations? Where are the breaks between the trends?

Technetium, element 43, has no values in the table. Predict the value of the property in your graph for technetium and write a brief explanation of how you did it. How accurate do you think your prediction might be? Explain your estimate.

Notes to the Teacher

After the students have completed their graphs, discuss the features of the graphs in the context of today's periodic table. In particular, point out how the trends segments match the horizontal periods in the table, that is atomic numbers 3-10, 10-18, 19-36 and 37-54. The maxima and minima of the trends mark the start or finish of periods.

Discuss graphic interpolation for predicting the properties of technetium with the students. This can be done by drawing a smooth line between the points before and after the point to be interpolated on the plot and then reading its value by drawing a vertical line from the atomic number of **Tc** intersecting the plot. Then drawing a horizontal line to the left axis gives the predicted value of the property.

Table 1. Selected Elements and Properties.

At.No.	Element	Symbol	M.P.°K	B.P.°K	Atomic Volume
1	Hydrogen	H	14	20	14.0
2	Helium	He	1	4	29.2
3	Lithium	Li	452	1600	13.0
4	Beryllium	Be	1560	2780	4.9
5	Boron	B	2310	2800	4.4
6	Carbon	C	3743	4620	6.2
7	Nitrogen	N	66	77	14.0
8	Oxygen	O	54	90	14.3
9	Fluorine	F	55	85	16.7
10	Neon	Ne	25	27	18.0
11	Sodium	Na	370	1162	23.6
12	Magnesium	Mg	923	1390	14.1

Table 1. Selected Elements and Properties (Contd.)

At.No.	Element	Symbol	M.P.°K	B.P.°K	Atomic Volume
13	Aluminum	Al	932	2600	10.0
14	Silicon	Si	1680	2950	11.4
15	Phosphorus	P	317	553	17.0
16	Sulfur	S	392	718	16.4
17	Chlorine	Cl	172	239	14.2
18	Argon	Ar	84	87	28.4
19	Potassium	K	337	1030	44.7
20	Calcium	Ca	1124	1760	25.9
21	Scandium	Sc	1670	4170	14.8
22	Titanium	Ti	2085	3550	10.7
23	Vanadium	V	2000	3650	8.5
24	Chromium	Cr	2170	2915	7.6
25	Manganese	Mn	1520	2360	7.4
26	Iron	Fe	1808	3070	7.1
27	Cobalt	Co	1770	3370	6.8
28	Nickel	Ni	1730	3070	6.7
29	Copper	Cu	1360	2855	7.1
30	Zinc	Zn	694	1180	9.2
31	Gallium	Ga	303	2260	11.8
32	Germanium	Ge	1230	3100	13.3
33	Arsenic	As	-------	800	13.0
34	Selenium	Se	490	958	18.5
35	Bromine	Br	266	332	24.9
36	Krypton	Kr	116	120	38.5
37	Rubidium	Rb	312	950	55.8
38	Strontium	Sr	1040	1657	34.5
39	Yttrium	Y	1770	3500	23.5
40	Zirconium	Zr	2125	3850	14.2
41	Niobium	Nb	2760	5400	11.0
42	Molybdenum	Mo	2880	5830	10.6
43	Technetium	Tc			
44	Ruthenium	Ru	2770	4380	8.4
45	Rhodium	Rh	2230	4230	8.5
46	Palladium	Pd	1820	3830	8.7
47	Silver	Ag	1234	2470	10.2
48	Cadmium	Cd	594	1040	13.0
49	Indium	In	430	2270	16.1
50	Tin	Sn	505	2600	16.3
51	Antimony	Sb	900	1710	18.2
52	Tellurium	Te	723	1360	21.2
53	Iodine	I	87	457	25.7
54	Xenon	Xe	116	165	29.0
55	Cesium	Cs	302	943	71.0

PERIODIC TRENDS IN THE PROPERTIES OF THE ELEMENTS

Paper and Pencil Exercise

--for the student--

Introduction

The Periodic Law states that the properties of elements are periodic functions of the atomic number of the element. Here the words "are functions of" mean "are determined by". The variation of properties is in some way determined by the variation in atomic number of the elements.

The recognition of periodic trends or patterns in the properties of elements was instrumental in the development of the periodic table. Later it was related to the electronic configuration of atoms. These periodic trends are easily seen if the values of the properties are plotted with the atomic numbers of the elements on a graph.

Purpose

The purpose of this exercise is to construct plots of some elemental properties to demonstrate the Periodic Law.

Procedure

Table 1 contains a selection of elements along with values of some of their properties. Your teacher will assign you one or two properties to plot. Set up your graph as follows:

1. On the horizontal axis place the atomic numbers for the elements in the table. The figure below illustrates how the assignment of values should be done. The smallest division on the graph paper should correspond to one unit of atomic number. Label the axis and place numbers every 5 or 10 units on the axis.
2. On the vertical axis plot the values of your assigned property. As shown in the figure, the maximum value should fall near the top of the graph paper and the minimum value near the bottom. Pay close attention to the correct assignment of the scale units. Label the axis.
3. Finally, make a dot on the graph for each set of values (atomic number, property) at the appropriate position according to the axes scales. Connect each dot to its nearest neighbor with a straight line segment. Notice that data are missing in some cases. When that happens, draw a dotted line on the graph.

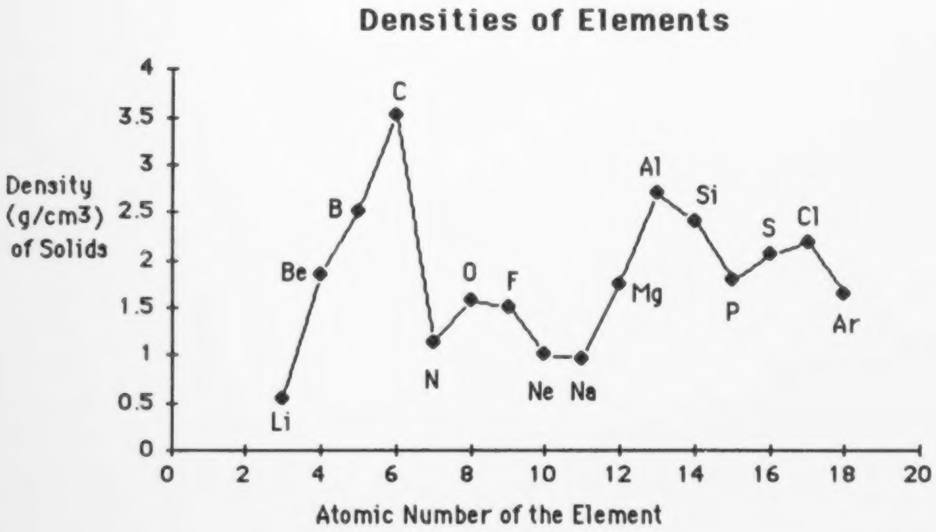


Figure 1. The Densities of Some Elements.

Analysis

Inspect the regions of your graph(s) between atomic numbers 3 through 10 and 10 through 18. How do they compare? Do the same for regions 19 through 36 and 37 through 54. How smooth are the variations? Where are the breaks between the trends?

Technetium, element 43, has no values in the table. Predict the value of the property in your graph for technetium and write a brief explanation of how you did it. How accurate do you think your prediction might be? Explain your estimate.

Table 1. Selected Elements and Properties.

At.No.	Element	Symbol	M.P.°K	B.P.°K	Atomic Volume
1	Hydrogen	H	14	20	14.0
2	Helium	He	1	4	29.2
3	Lithium	Li	452	1600	13.0
4	Beryllium	Be	1560	2780	4.9
5	Boron	B	2310	2800	4.4
6	Carbon	C	3743	4620	6.2
7	Nitrogen	N	66	77	14.0
8	Oxygen	O	54	90	14.3
9	Fluorine	F	55	85	16.7
10	Neon	Ne	25	27	18.0
11	Sodium	Na	370	1162	23.6
12	Magnesium	Mg	923	1390	14.1
13	Aluminum	Al	932	2600	10.0
14	Silicon	Si	1680	2950	11.4
15	Phosphorus	P	317	553	17.0
16	Sulfur	S	392	718	16.4
17	Chlorine	Cl	172	239	14.2
18	Argon	Ar	84	87	28.4
19	Potassium	K	337	1030	44.7
20	Calcium	Ca	1124	1760	25.9
21	Scandium	Sc	1670	4170	14.8
22	Titanium	Ti	2085	3550	10.7
23	Vanadium	V	2000	3650	8.5
24	Chromium	Cr	2170	2915	7.6
25	Manganese	Mn	1520	2360	7.4
26	Iron	Fe	1808	3070	7.1

Table 1. Selected Elements and Properties (Contd.)

At.No.	Element	Symbol	M.P.°K	B.P.°K	Atomic Volume
27	Cobalt	Co	1770	3370	6.8
28	Nickel	Ni	1730	3070	6.7
29	Copper	Cu	1360	2855	7.1
30	Zinc	Zn	694	1180	9.2
31	Gallium	Ga	303	2260	11.8
32	Germanium	Ge	1230	3100	13.3
33	Arsenic	As	-------	800	13.0
34	Selenium	Se	490	958	18.5
35	Bromine	Br	266	332	24.9
36	Krypton	Kr	116	120	38.5
37	Rubidium	Rb	312	950	55.8
38	Strontium	Sr	1040	1657	34.5
39	Yttrium	Y	1770	3500	23.5
40	Zirconium	Zr	2125	3850	14.2
41	Niobium	Nb	2760	5400	11.0
42	Molybdenum	Mo	2880	5830	10.6
43	Technetium	Tc			
44	Ruthenium	Ru	2770	4380	8.4
45	Rhodium	Rh	2230	4230	8.5
46	Palladium	Pd	1820	3830	8.7
47	Silver	Ag	1234	2470	10.2
48	Cadmium	Cd	594	1040	13.0
49	Indium	In	430	2270	16.1
50	Tin	Sn	505	2600	16.3
51	Antimony	Sb	900	1710	18.2
52	Tellurium	Te	723	1360	21.2
53	Iodine	I	87	457	25.7
54	Xenon	Xe	116	165	29.0
55	Cesium	Cs	302	943	71.0

THE PERIODIC TABLE

Laboratory Exercise
--for the teacher--

Introduction

It is largely due to the regular changes in oxidation number electronic configuration among the elements in the periodic table that the periodic variations in their properties exist. We must remember that the early workers we've described knew nothing about electronic configurations - indeed the electron was not even discovered until several decades after Mendeleev first published his table! Only a limited number of physical and chemical properties were available to be studied making the work more difficult and the results Mendeleev obtained all the more impressive.

Prelaboratory Discussion

Note: Students should have completed the pencil and paper exercise on periodic trends in the properties of elements before beginning this exercise.

It is important that your students learn something of how scientists think about the problems they attack. A vital part of teaching this subject is to give students exercises which require them to attack similar problems (scaled down, of course). In this way they experience first hand the nature of the problem and the thought processes needed to solve it.

This laboratory exercise gives your students a chance to tackle the job of arranging a selection of Main Group elements into the rows and columns of Mendeleev's periodic table. The elements in the exercise are identified only by letters along with a few physical and chemical properties listed on a card for each element. Two sample cards are shown below.

Element: a **Atomic No.** 3

Physical Properties: Metal
Melting Point: 180°C
Boiling Point: 1336°C
Density:
Chemical Properties
Oxide(s): M_2O

Element: b **Atomic No.**

Physical Properties: Metal
Melting Point: 850°C
Boiling Point:
Density: 1.55 g/cm^3
Chemical Properties
Oxide(s): MO

Notice that for element "a", the atomic number is given as are some physical properties and the formula "M_2O" for the oxide of the element. The density is missing for this element but is given for element "b" but other properties are missing for "b". This is done to simulate how things were when Mendeleev worked on the table - many properties were not known.

In your prelaboratory discussion, first explain to your students that their goal is to arrange the element cards correctly into a portion of the periodic table. In order to make this arrangement, the students will have to consider three types of information from the element cards:

1. the atomic number, if given,
2. the physical properties, and
3. the chemical property (formula).

First, if the atomic number is given, they should compare it to the full periodic table to determine the position of the element in the working table. Second they should determine from the chemical formula which group(s) in the periodic table might contain the element in question. For example, the formula of element "a" indicates that element's oxidation state or valence is 1 which means it must come from Group 1 or Group 17 in the table. Third, considering the metal - nonmetal distinction in the physical properties helps narrow down the choice of group. Element "a" is identified as a metal. Metals are found in Group 1 but not Group 17 so "a" must be from Group 1. This conclusion is verified, of course, by the atomic number which identifies element "a" as lithium, **Li**.

Once all the lettered elements are assigned to groups, the remaining physical properties, melting and boiling points and densities are used to order the elements within the group. The students should look for smooth trends in these propeties considering the values of known elements to determine whether the properties increase or decrease down the group. For example, the melting points of the Group 1 elements **decrease** down the group while those of group 18 **increase** down the group.

In the second part of the exercise, you will need to provide samples of three elements in vials for the students to examine. These vials should be sealed with plastic tape so the students do not open them. Separate cards are provided for these elements but the students will decide whether each element appears to be metallic or nonmetallic. This part of the exercise should not be started until the first part has been finished.

Procedure (Teacher)

Provide scissors for the students to use in cutting out the elements cards before beginning the exercise. Each student should have a set of cards and enough table space to lay out the cards. This is the most effective way to carry out the exercise.

To prepare the unknown element samples, first place a small piece of aluminum foil in vial No.1, cap it and seal the cap with tape. This is meant to represent tin foil which looks the same but is harder to find. (Tin foil was used in world war II because all the aluminum was used in the war effort.) Take the second vial to the chemistry laboratory in your school and ask your colleague there for a small amount of powdered sulfur. If you don't have access to a chemistry lab, buy a small bottle of Flowers of Sulfur from a pharmacy and place some in the vial, then cap and seal it with tape. Vial No.3 is supposed to contain krypton, a colorless, odorless gas indistinguishable from air, so you need only cap and seal the vial. The students will observe a colorless gas which is satisfactory for our purposes.

Instruct the students not to fill out the blank periodic table in their exercise until they have finished putting their cards in position. The students should be able to finish the first part of the exercise in 30 to 45 minutes and the second part in 15-20 minutes. It is useful to let the students work in groups of two or three as they try to reason out the positions of the elements. Each student should submit his or her own results for grading however since there may not always be agreement on all the element positions.

Note: If you wish to have a smaller set of unknown elements in part one of the exercise, one or more groups of elements can be removed from consideration by simply identifying them for the students. For example, Group 13 could be eliminated by identifying elements e, d and x as **B**, **Al**, and **Ga**. It is probably better not to eliminate Groups 14, 16 or 18 because the unknowns in the second part of the exercise come from those groups.

Part 1

In order to better understand the table, you will have an opportunity in this laboratory exercise to construct a segment of the table starting from cards bearing some information on the properties of elements. The elements will not be identified for you so it will be necessary to use the properties listed to construct your table.

Mendeleev studied two types of properties to discover the patterns of the periodic table. First, there were the **oxidation numbers** of the elements which were determined from the **formulas** of their compounds. Oxygen was assigned an oxidation number of **-2**. An example of how this was done uses the compound calcium oxide. The formula of the compound is **CaO**. Since the compound has an overall charge of zero, it follows that the oxidation number of calcium must be **+2**.

$$+2(\mathrm{Ca}) + (-2)(\mathrm{O}) = 0(\mathrm{CaO})$$

In this way the oxidation numbers were determined for many elements and it was found that elements in periodic table groups exhibit the same oxidation numbers. The table below shows the oxidation numbers for the Main Groups.

Group No.:	1	2	13	14	15	16	17	18
Oxid. No. :	+1	+2	+3	+4,-4	-3	-2	-1	0

In order to assign the element on a card to a group in the table, you should consider the oxidation number of the element.

The second thing to study is the physical properties of the elements within each group in order to arrange them in the proper order. Here things are not always as clearcut as was the case with oxidation numbers. For example, look at the variation of melting points in the elements listed below.

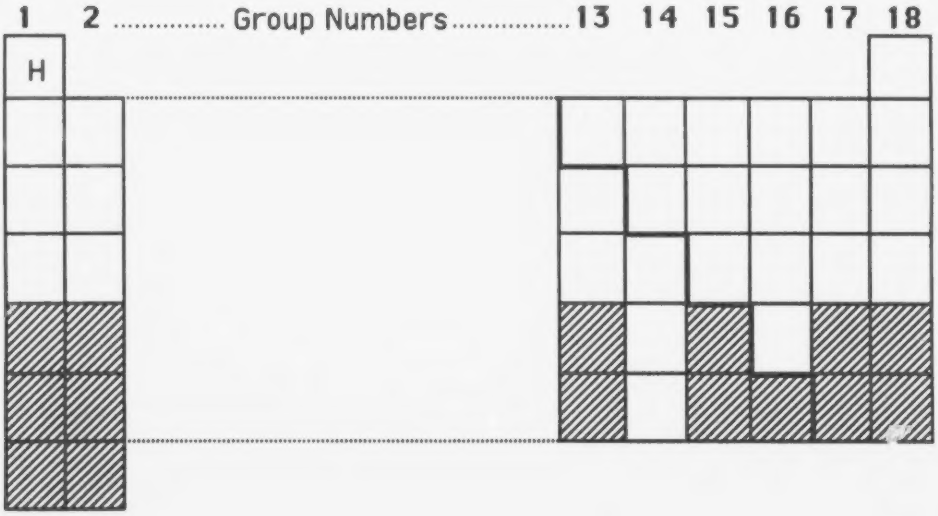
Element:	Lithium	Sodium	Potassium	Rubidium	Cesium
m.p.°C	180	98	63	38.8	28.7

Element:	Oxygen	Sulfur	Selenium	Tellurium	Polonium
m.p.°C	-219	113	217	450	254

Notice that the melting points of the elements in the first group decrease regularly from left to right whereas those in the second group increase regularly (except for the last element, polonium). Usually when trends in several properties are compared, however, the correct order of elements can be determined.

Procedure

1. Cut out the element cards and try to separate them into periodic table groups, assigning the correct number to each.
2. Consider the properties of the elements in each group and try to arrange the elements in order of increasing atomic number.
3. On a separate sheet of paper, sketch your periodic table starting with the diagram below and using the lower case letters in place of the normal symbols for the elements on the cards. (For simplicity the elements shaded in the diagram are not included in this exercise.)



Hints: The atomic numbers are given on some cards to help you identify the elements. Only Main Group elements are included but some of those were omitted for later consideration in the second part of this exercise. You should realize that not all the trends in properties vary in perfect order so it may be necessary to use density in one Group, melting point in another, etc..

Part 2

You will be able to examine samples of some elements in glass vials along with a card bearing some properties of the element. The elements correspond to "empty spots" left in your table from part 1. Observe each sample, consider its properties and try to identify the element.

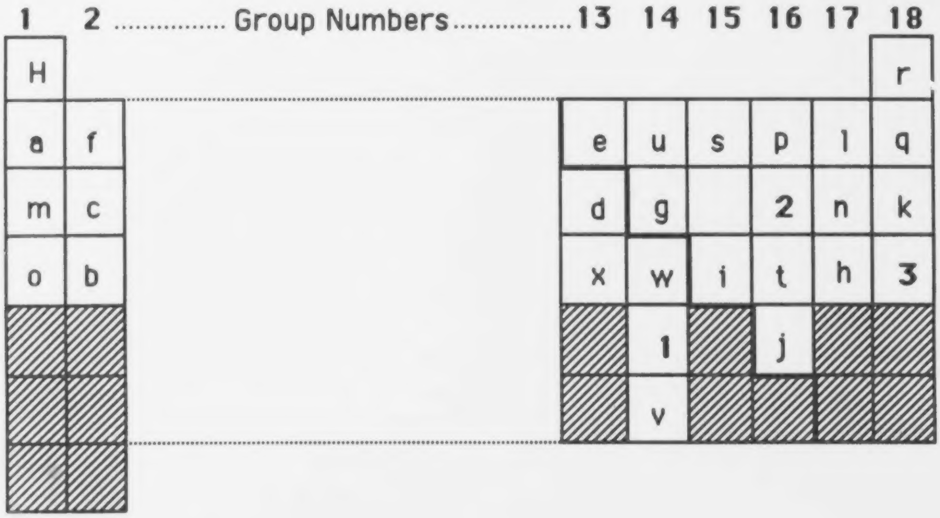
Conclusion

You should be able to conclude from this exercise how early workers used the chemical and physical properties of the elements to develop the periodic table. Another conclusion you should reach is how Mendeleev was able to use the periodic table to predict the properties of undiscovered elements. Review the pencil and paper exercise on periodic trends in the properties of elements if the latter point is not clear to you.

Postlaboratory Discussion

After the students have finished the exercise and handed in their results, take a few minutes to show them the correct results from the table below and draw them into a discussion of the techniques they used to solve the ordering of the elements in their table. In particular, if they made mistakes, discuss how they should have arrived at the correct answers using the chemical properties and metal - nonmetal characteristics for group placement and the other physical properties for ordering within the group. Ask a different student to explain how he or she arrived at the elements for each of the eight periodic table groups considered.

It is important here that you have done the exercise yourself before you discuss it with your students.



Element Cards

Element: a **Atomic No. 3**

Physical Properties: Metal
Melting Point:180°C
Boiling Point: 1336°C
Density:
Chemical Properties
Oxide(s): M_2O

Element: b **Atomic No.**

Physical Properties: Metal
Melting Point: 850°C
Boiling Point:
Density: 1.55 g/cm^3
Chemical Properties
Oxide(s): MO

Element: c **Atomic No.**

Physical Properties: Metal
Melting Point:
Boiling Point:
Density: 1.74 g/cm^3

Chemical Properties
Oxide(s): MO

Element: d **Atomic No.**

Physical Properties: Semimetal
Melting Point: 660°C
Boiling Point
Density:

Chemical Properties
Oxide(s): M_2O_3

Element: e **Atomic No.**

Physical Properties: Semimetal
Melting Point: 2300°C
Boiling Point: 2550°C
Density:

Chemical Properties
Oxide(s): M_2O_3

Element: f **Atomic No. 4**

Physical Properties: Metal
Melting Point:
Boiling Point:
Density: 1.85 g/cm^3

Chemical Properties
Oxide(s): MO

Element: g **Atomic No. 14**

Physical Properties: Semimetal
Melting Point: 1420°C
Boiling Point:
Density: 2.4 g/cm^3

Chemical Properties
Oxide(s): MO_2

Element: h **Atomic No.**

Physical Properties: Nonmetal
Melting Point: -73°C
Boiling Point: 59°C
Density:

Chemical Properties
Oxide(s): E_2O

Element: i **Atomic No.** 33

Physical Properties: Semimetal
Melting Point:
Boiling Point: 800°C
Density: 2.0 g/cm^3

Chemical Properties
Oxide(s): M_2O_3, M_2O_5

Element: j **Atomic No.**

Physical Properties: Semimetal
Melting Point: 450°C
Boiling Point: 987°C
Density: 6.2 g/cm^3

Chemical Properties
Oxide(s): MO_2, MO_3

Element: k **Atomic No.** 18

Physical Properties: Nonmetal
Melting Point: -189°C
Boiling Point: -186
Density: 1.78 g/L

Chemical Properties
Oxide(s): none

Element: l **Atomic No.** 9

Physical Properties: Nonmetal
Melting Point: -223°C
Boiling Point: -187°C
Density:

Chemical Properties
Oxide(s): E_2O

Element: m **Atomic No.**

Physical Properties: Metal
Melting Point: 98°C
Boiling Point: 880°C
Density:

Chemical Properties
Oxide(s): M_2O

Element: n **Atomic No.**

Physical Properties: Nonmetal
Melting Point: -102°C
Boiling Point: -35°C
Density:

Chemical Properties
Oxide(s): E_2O

Element: o **Atomic No.**

Physical Properties: Metal
Melting Point: 63°C
Boiling Point: 760°C
Density:

Chemical Properties
Oxide(s): M_2O

Element: p **Atomic No.**

Physical Properties: Nonmetal
Melting Point: -219°C
Boiling Point: -183°C
Density: 1.43°C

Chemical Properties
Oxide(s): EO

Element: q **Atomic No.** 10

Physical Properties: Nonmetal
Melting Point: -249°C
Boiling Point: -246°C
Density: 0.9 g/L

Chemical Properties
Oxide(s): None

Element: r **Atomic No.**

Physical Properties: Nonmetal
Melting Point: -272°C
Boiling Point: -269°C
Density:

Chemical Properties
Oxide(s): None

Element: s **Atomic No.**

Physical Properties: Nonmetal
Melting Point: -210°C
Boiling Point: -186°C
Density: 1.25 g/L

Chemical Properties
Oxide(s): E_2O_3, E_2O_5

Element: t **Atomic No.**

Physical Properties: Nonmetal
Melting Point: 217°C
Boiling Point: 685°C
Density: 4.5 g/cm^3

Chemical Properties
Oxide(s): EO_2, EO_3

Element: u **Atomic No.**

Physical Properties: Nonmetal
Melting Point: 3500°C
Boiling Point:
Density:

Chemical Properties
Oxide(s): EO, EO_2

Element: v **Atomic No.**

Physical Properties: Metal
Melting Point: 327°C
Boiling Point:
Density:

Chemical Properties
Oxide(s): MO, MO_2

Element: w **Atomic No.**

Physical Properties: Semimetal
Melting Point: 938°C
Boiling Point:
Density: 5.36 g/cm^3

Chemical Properties
Oxide(s): MO_2

Element: x **Atomic No.** 31

Physical Properties: Metal
Melting Point: 30°C
Boiling Point:
Density:

Chemical Properties
Oxide(s): M_2O_3

Unknown Sample Cards

Element: 1 **Atomic No.**

Physical Properties:
Melting Point: 832°C
Boiling Point:
Density: 5.75 g/cm^3

Chemical Properties
Oxide(s): MO_2

Element: 2 **Atomic No.**

Physical Properties:
Melting Point: 119°C
Boiling Point:
Density: 2.07 g/cm^3

Chemical Properties
Oxide(s): EO_2, EO_3

Element: 3 **Atomic No.**

Physical Properties:
Melting Point: -157°C
Boiling Point: -153°C
Density:

Chemical Properties
Oxide(s): None

THE PERIODIC TABLE

Laboratory Exercise

--for the student--

Introduction

It is largely due to the regular changes in oxidation number electronic configuration among the elements in the periodic table that the periodic variations in their properties exist. We must remember that the early workers we've described knew nothing about electronic configurations - indeed the electron was not even discovered until several decades after Mendeleev first published his table! Only a limited number of physical and chemical properties were available to be studied making the work more difficult and the results Mendeleev obtained all the more impressive.

Part 1

In order to better understand the table, you will have an opportunity in this laboratory exercise to construct a segment of the table starting from cards bearing some information on the properties of elements. The elements will not be identified for you so it will be necessary to use the properties listed to construct your table.

Mendeleev studied two types of properties to discover the patterns of the periodic table. First, there were the **oxidation numbers** of the elements which were determined from the **formulas** of their compounds. Oxygen was assigned an oxidation number of **-2**. An example of how this was done uses the compound calcium oxide. The formula of the compound is **CaO**. Since the compound has an overall charge of zero, it follows that the oxidation number of calcium must be **+2**.

$$+2(\mathrm{Ca}) + (-2)(\mathrm{O}) = 0(\mathrm{CaO})$$

In this way the oxidation numbers were determined for many elements and it was found that elements in periodic table groups exhibit the same oxidation numbers. The table below shows the oxidation numbers for the Main Groups.

Group No.:	1	2	13	14	15	16	17	18
Oxid. No. :	+1	+2	+3	+4,-4	-3	-2	-1	0

In order to assign the element on a card to a group in the table, you should consider the oxidation number of the element.

The second thing to study is the physical properties of the elements within each group in order to arrange them in the proper order. Here things are not always as clearcut as was the case with oxidation numbers. For example, look at the variation of melting points in the elements listed below.

Element:	Lithium	Sodium	Potassium	Rubidium	Cesium
m.p.°C	180	98	63	38.8	28.7

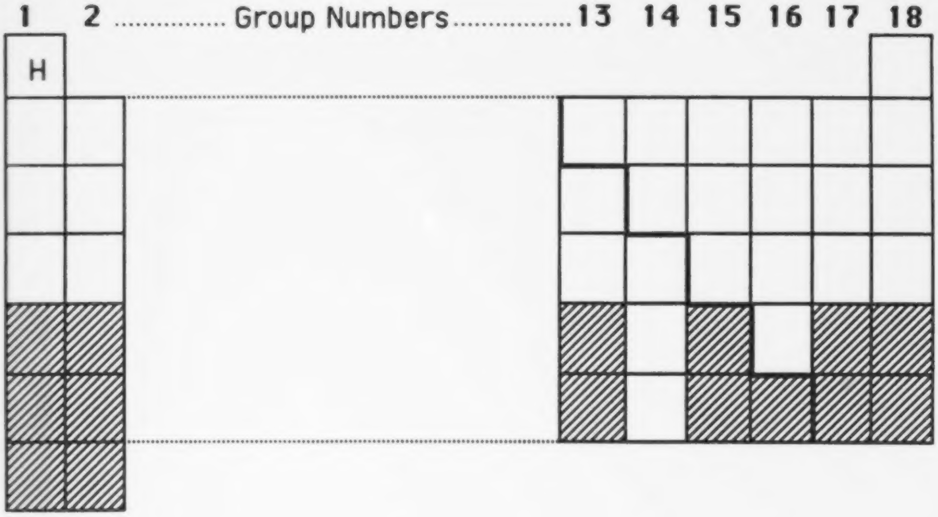
Element:	Oxygen	Sulfur	Selenium	Tellurium	Polonium
m.p.°C	-219	113	217	450	254

Notice that the melting points of the elements in the first group decrease regularly from left to right whereas those in the second group increase regularly (except for the last element, polonium). Usually when trends in several properties are compared, however, the correct order of elements can be determined.

Procedure

1. Cut out the element cards and try to separate them into periodic table groups, assigning the correct number to each.

2. Consider the properties of the elements in each group and try to arrange the elements in order of increasing atomic number.
3. On a separate sheet of paper, sketch your periodic table starting with the diagram below and using the lower case letters in place of the normal symbols for the elements on the cards. (For simplicity the elements shaded in the diagram are not included in this exercise.)



Hints: The atomic numbers are given on some cards to help you identify the elements. Only Main Group elements are included but some of those were omitted for later consideration in the second part of this exercise. You should realize that not all the trends in properties vary in perfect order so it may be necessary to use density in one Group, melting point in another, etc..

Part 2

You will be able to examine samples of some elements in glass vials along with a card bearing some properties of the element. The elements correspond to "empty spots" left in your table from part 1. Observe each sample, consider its properties and try to identify the element.

Conclusion

You should be able to conclude from this exercise how early workers used the chemical and physical properties of the elements to develop the periodic table. Another conclusion you should reach is how Mendeleev was able to use the periodic table to predict the properties of undiscovered elements. Review the pencil and paper exercise on periodic trends in the properties of elements if the latter point is not clear to you.

Element Cards

Element: a **Atomic No.** 3

Physical Properties: Metal
Melting Point:180°C
Boiling Point: 1336°C
Density:

Chemical Properties
Oxide(s): M_2O

Element: b **Atomic No.**

Physical Properties: Metal
Melting Point: 850°C
Boiling Point:
Density: 1.55 g/cm^3

Chemical Properties
Oxide(s): MO

Element: c **Atomic No.**

Physical Properties: Metal
Melting Point:
Boiling Point:
Density: 1.74 g/cm^3

Chemical PropertiesChemical Properties
Oxide(s): MO

Element: d **Atomic No.**

Physical Properties: Semimetal
Melting Point: 660°C
Boiling Point:
Density:

Oxide(s): M_2O_3

Element: e **Atomic No.**

Physical Properties: Semimetal
Melting Point: 2300°C
Boiling Point: 2550°C
Density:

Chemical Properties
Oxide(s): M_2O_3

Element: f **Atomic No.** 4

Physical Properties: Metal
Melting Point:
Boiling Point:
Density: 1.85 g/cm^3

Chemical Properties
Oxide(s): MO

Element: g **Atomic No.** 14

Physical Properties: Semimetal
Melting Point: 1420°C
Boiling Point:
Density: 2.4 g/cm^3

Chemical Properties
Oxide(s): MO_2

Element: h **Atomic No.**

Physical Properties: Nonmetal
Melting Point: -73°C
Boiling Point: 59°C
Density:

Chemical Properties
Oxide(s): E_2O

Element: i **Atomic No.** 33

Physical Properties: Semimetal
Melting Point:
Boiling Point: 800°C
Density: 2.0 g/cm^3

Chemical Properties
Oxide(s): M_2O_3, M_2O_5

Element: j **Atomic No.**

Physical Properties: Semimetal
Melting Point: 450°C
Boiling Point: 987°C
Density: 6.2 g/cm^3

Chemical Properties
Oxide(s): MO_2, MO_3

Element: k **Atomic No.** 18

Physical Properties: Nonmetal
Melting Point: -189°C
Boiling Point: -186
Density: 1.78 g/L

Chemical Properties
Oxide(s): none

Element: l **Atomic No.** 9

Physical Properties: Nonmetal
Melting Point: -223°C
Boiling Point: -187°C
Density:

Chemical Properties
Oxide(s): E_2O

Element: m **Atomic No.**

Physical Properties: Metal
Melting Point: 98°C
Boiling Point: 880°C
Density:

Chemical Properties
Oxide(s): M_2O

Element: n **Atomic No.**

Physical Properties: Nonmetal
Melting Point: -102°C
Boiling Point: -35°C
Density:

Chemical Properties
Oxide(s): E_2O

Element: o **Atomic No.**

Physical Properties: Metal
Melting Point: 63°C
Boiling Point: 760°C
Density:

Chemical Properties
Oxide(s): M_2O

Element: p **Atomic No.**

Physical Properties: Nonmetal
Melting Point: -219°C
Boiling Point: -183°C
Density: 1.43°C

Chemical Properties
Oxide(s): EO

Element: q **Atomic No.** 10

Physical Properties: Nonmetal
Melting Point: -249°C
Boiling Point: -246°C
Density: 0.9 g/L

Chemical Properties
Oxide(s): None

Element: r **Atomic No.**

Physical Properties: Nonmetal
Melting Point: -272°C
Boiling Point: -269°C
Density:

Chemical Properties
Oxide(s): None

Element: s **Atomic No.**

Physical Properties: Nonmetal
Melting Point: -210°C
Boiling Point: -186°C
Density: 1.25 g/L

Chemical Properties
Oxide(s): E_2O_3, E_2O_5

Element: t **Atomic No.**

Physical Properties: Nonmetal
Melting Point: 217°C
Boiling Point: 685°C
Density: 4.5 g/cm^3

Chemical Properties
Oxide(s): EO_2, EO_3

Element: u **Atomic No.**

Physical Properties: Nonmetal
Melting Point: 3500°C
Boiling Point:
Density:

Chemical Properties
Oxide(s): EO, EO_2

Element: v **Atomic No.**

Physical Properties: Metal
Melting Point: 327°C
Boiling Point:
Density:

Chemical Properties
Oxide(s): MO, MO_2

Element: w **Atomic No.**

Physical Properties: Semimetal
Melting Point: 938°C
Boiling Point:
Density: 5.36 g/cm^3

Chemical Properties
Oxide(s): MO_2

Element: x **Atomic No.** 31

Physical Properties: Metal
Melting Point: 30°C
Boiling Point:
Density:

Chemical Properties
Oxide(s): M_2O_3

Unknown Sample Cards

Element: 1 **Atomic No.**

Physical Properties:
Melting Point: 832°C
Boiling Point:
Density: 5.75 g/cm^3

Chemical Properties
Oxide(s): MO_2

Element: 2 **Atomic No.**

Physical Properties:
Melting Point: 119°C
Boiling Point:
Density: 2.07 g/cm^3

Chemical Properties
Oxide(s): EO_2, EO_3

Element: 3 **Atomic No.**

Physical Properties:
Melting Point: -157°C
Boiling Point: -153°C
Density:

Chemical Properties
Oxide(s): None

Chemical Compounds and Equations 5

Background Information

Once youngsters learn the alphabet, they are ready to write words and construct sentences. Similarly, once chemistry students learn the chemical symbols, they are ready to write formulas, name compounds and balance chemical equations. This knowledge is necessary in order for students to understand what takes place during chemical changes and to communicate in the language of chemistry. Physical science students need much practice to gain competence in this most basic area of chemistry. It is similar to teaching them to read and write a foreign language, which requires drill and repetition. Once students learn to write formulas, name compounds, and balance equations, they feel confident about their ability to communicate in "basic chemistry." They have some important knowledge to help them in many other science courses. We will begin the study of this unit with writing chemical formulas.

To write the chemical formula for a compound formed by two elements having different oxidation numbers, such as aluminum and oxygen, the following steps are taken.

1. Write the symbols of the elements. The element with the positive oxidation number is written first.

$$\text{Al} \qquad\qquad \text{O}$$

2. Note the oxidation number of each element above the symbol.

$$\overset{+3}{\text{Al}} \qquad\qquad \overset{-2}{\text{O}}$$

3. Since the total number of negative charges must balance the positive charges, we need two aluminum atoms with a charge of +3 to balance three oxygen atoms with a charge of -2. To determine this, ask the student "What is the smallest number each of these oxidation numbers will go into an even number of times?" (the least common multiple). The smallest number into which +3 and -2 will go into is 6. Since aluminum's oxidation number, +3, will go into 6 two times, we will need two atoms of aluminum. Since oxygen's oxidation number, -2, will go into 6 three times, we will need three atoms of oxygen. Thus the formula is Al_2O_3.

An alternate method is to "drop" the signs and "crisscross" the oxidation numbers. This will give the correct subscripts for the formula in some instances.

$$\overset{+3}{\text{Al}} \qquad\qquad \overset{-2}{\text{O}}$$

$$Al_2O_3$$

Caution! The crisscross method does not promote understanding and often leads to error in writing formulas correctly. The examples below should make this obvious.

4. To write the formula for compounds formed by two elements having the same oxidation numbers, it is not necessary to "crisscross" or find the least common multiple since one element will lose the exact number of electrons that the other element needs to gain to form a compound.

Thus

$\overset{+1}{\text{Na}} \quad \overset{-1}{\text{Cl}}$ $\qquad$ $\overset{+2}{\text{Ca}} \quad \overset{-2}{\text{S}}$

NaCl $\qquad$ CaS

5. It is never necessary to write the number "1" in a formula. The "1" is understood. Thus carbon dioxide is written:

Write the symbols: C O
Note the oxidation numbers: $\overset{+4}{\text{C}} \quad \overset{-2}{\text{O}}$
Find the least common multiple: 4
Divide each oxidation number into 4. Four goes into four once so we use one atom of carbon. Two goes into four twice, so we use two atoms of oxygen.
Write the subscript: CO_2
Carbon needs no subscript since the one is understood. Oxygen has a subscript of two.

6. To write the formula for a compound containing a polyatomic ion, use the same procedure. Treat the polyatomic ion as if it were a single element. Thus calcium nitrate is written as follows:

Write the symbols: Ca NO_3
Note the oxidation numbers: $\overset{+2}{\text{Ca}} \quad \overset{-1}{\text{NO}_3}$
Find the least common multiple or "crisscross" the oxidation numbers: Ca $NO_{3\ 2}$
Point out that because the "2" applies to the entire nitrate ion, it is necessary to put the ion in parenthesis. Thus $Ca(NO_3)_2$

7. It is necessary to stress the use of the parenthesis when using a subscript after the hydroxide polyatomic ion (OH). Thus KOH and NaOH represent potassium hydroxide and sodium hydroxide. $Ca(OH)_2$ is calcium hydroxide.

Much practice is needed for the physical science student to "master" formula writing before going on to equations.

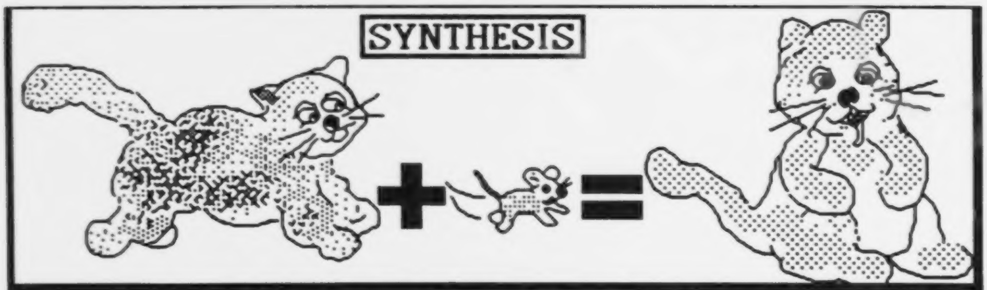
Three conditions must be satisfied in writing equations: (a) the equation must represent the facts; (b) the equation must include all of the symbols and formulas of the reactants and products; and (c) the law of conservation of mass must be satisfied. With physical science students it is usually necessary to introduce these conditions independently and to drill on them one at a time. There is a quantum leap between the excitement of seeing a reaction occur in the lab and the expression of this reaction in a complete, balanced chemical equation by the younger student. The mechanics of balancing equations by using the correct coefficients in equations which have the facts and the formulas supplied by the teacher may be the easiest place to start. This exposes the student to a number of chemical equations in which the form is correct and may start to shape his/her thinking.

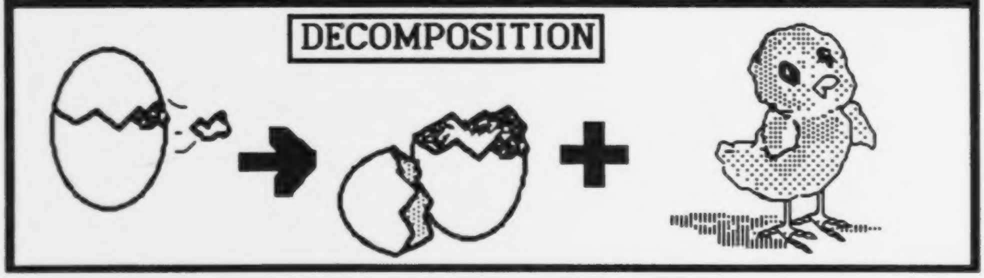
Another technique which may help bridge the gap between what the student observes and the complete, balanced equation is to begin equation writing with word equations. Verbalization is an important step in the learning process, especially when you expect students to manipulate very abstract concepts. When students are able to describe chemical reactions using the proper symbols and terms, they will be in a better position to observe and appreciate them in the laboratory.

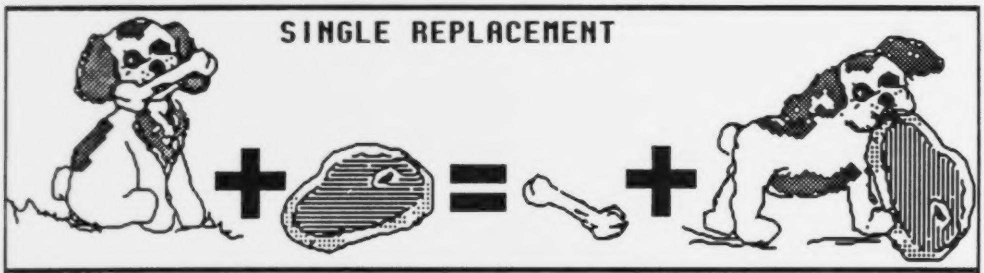
A PICTURE IS WORTH A THOUSAND WORDS
Student Project

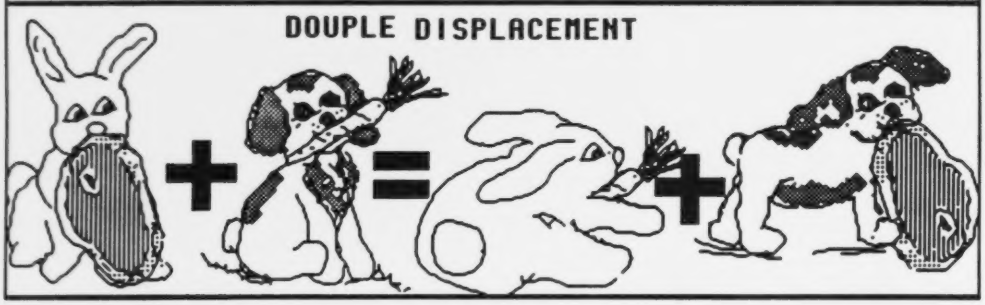
For many students who begin the study of chemistry, symbols marching across the board mean little or nothing. They do not have a single clue as to how "you" knew "those" would be the products. A cartoon approach reaches many students and it makes the subject matter more concrete and interesting. It also livens up the classroom and bulletin boards for weeks to come. Just get students started and they will take off on this project.

See the example of one of these projects. You can make overhead transparencies of some of the students' drawings for discussion in class. The students derive a great deal out of attempting to interpret the drawings. This exercise reinforces the type of reactions that occur in chemistry.









NAMING CHEMICAL COMPOUNDS

Paper and Pencil Exercise
-- for the teacher --

Give the names of the following compounds:

1.	$LiNO_3$	lithium nitrate	
2.	CaO	calcium oxide	
3.	$NaOH$	sodium hydroxide	
4.	HCl	hydrochloric acid	(hydrogen chloride)
5.	AlI_3	aluminum iodide	
6.	$CuCO_3$	copper (II) carbonate	
7.	$SnCl_2$	tin (II) chloride	
8.	HgI_2	mercury (II) iodide	
9.	NH_4Cl	ammonium chloride	
10.	Fe_2S_3	iron (III) sulfide	
11.	$BaSO_4$	barium sulfate	
12.	$Zn_3(PO_4)_2$	zinc phosphate	
13.	H_2SO_4	sulfuric acid	(hydrogen sulfate)
14.	$Mg(HCO_3)_2$	magnesium bicarbonate	
15.	$AgBr$	silver bromide	
16.	$Ca(NO_3)_2$	calcium nitrate	
17.	MnO_2	manganese (IV) oxide	

NAMING CHEMICAL COMPOUNDS

Paper and Pencil Exercise

-- for the student --

Give the names of the following compounds:

1. $LiNO_3$ ________________
2. CaO ________________
3. $NaOH$ ________________
4. HCl ________________
5. AlI_3 ________________
6. $CuCO_3$ ________________
7. $SnCl_2$ ________________
8. HgI_2 ________________
9. NH_4Cl ________________
10. Fe_2S_3 ________________
11. $BaSO_4$ ________________
12. $Zn_3(PO_4)_2$ ________________
13. H_2SO_4 ________________
14. $Mg(HCO_3)_2$ ________________
15. $AgBr$ ________________
16. $Ca(NO_3)_2$ ________________
17. MnO_2 ________________

WRITING FORMULAS

Paper and Pencil Exercise
-- for the teacher --

Use a periodic chart or an oxidation list to write formulas for the following compounds.

1.	aluminum fluoride	AlF_3
2.	zinc bromide	$ZnBr_2$
3.	aluminum nitride	AlN
4.	silver sulfide	Ag_2S
5.	zinc oxide	ZnO
6.	mercury (II) oxide	HgO
7.	silver chloride	$AgCl$
8.	calcium hydroxide	$Ca(OH)_2$
9.	ammonium hydroxide	NH_4OH
10.	iron (III) sulfide	Fe_2S_3
11.	potassium chlorate	$KClO_3$
12.	sodium bicarbonate	$NaHCO_3$
13.	silver nitrate	$AgNO_3$
14.	aluminum sulfate	$Al_2(SO_4)_3$
15.	lead (IV) oxide	PbO_2
16.	calcium phosphate	$Ca_3(PO_4)_2$
17.	carbon tetrachloride	CCl_4
18.	sulfur dioxide	SO_2
19.	lithium hydroxide	$LiOH$
20.	hydrogen peroxide	H_2O_2

WRITING FORMULAS

Paper and Pencil Exercise

-- for the student --

Use a periodic chart or an oxidation list to write formulas for the following compounds.

1. aluminum fluoride ____________________
2. zinc bromide ____________________
3. aluminum nitride ____________________
4. silver sulfide ____________________
5. zinc oxide ____________________
6. mercury (II) oxide ____________________
7. silver chloride ____________________
8. calcium hydroxide ____________________
9. ammonium hydroxide ____________________
10. iron (III) sulfide ____________________
11. potassium chlorate ____________________
12. sodium bicarbonate ____________________
13. silver nitrate ____________________
14. aluminum sulfate ____________________
15. lead (IV) oxide ____________________
16. calcium phosphate ____________________
17. carbon tetrachloride ____________________
18. sulfur dioxide ____________________
19. lithium hydroxide ____________________
20. hydrogen peroxide ____________________

BALANCING CHEMICAL EQUATIONS

Paper and Pencil Exercise

-- for the teacher --

Supply the coefficients which will balance the following:

(a) $\underline{\ 2\ }\ K + \underline{\ 2\ }\ H_2O \rightarrow \underline{\ 2\ }\ KOH + \underline{\quad}\ H_2$

(b) $\underline{\ 4\ }\ Fe + \underline{\ 3\ }\ O_2 \rightarrow \underline{\ 2\ }\ Fe_2O_3$

(c) $\underline{\quad}\ NaHCO_3 \rightarrow \underline{\quad}\ CO_2 + \underline{\quad}\ NaOH$

(d) $\underline{\quad}\ Fe(OH)_3 + \underline{\ 3\ }\ HNO_3 \rightarrow \underline{\quad}\ Fe(NO_3)_3 + \underline{\ 3\ }\ H_2O$

(e) $\underline{\quad}\ Cu + \underline{\quad}\ H_2SO_4 \rightarrow \underline{\quad}\ CuSO_4 + \underline{\quad}\ H_2$

(f) $\underline{\ 2\ }\ C_2H_2 + \underline{\ 5\ }\ O_2 \rightarrow \underline{\ 4\ }\ CO_2 + \underline{\ 2\ }\ H_2O$

(g) $\underline{\ 2\ }\ H_2O_2 \rightarrow \underline{\ 2\ }\ H_2O + \underline{\quad}\ O_2$

(h) $\underline{\ 2\ }\ HgO \rightarrow \underline{\ 2\ }\ Hg + \underline{\quad}\ O_2$

(i) $\underline{\ 3\ }\ Mg + \underline{\ 2\ }\ FeCl_3 \rightarrow \underline{\ 3\ }\ MgCl_2 + \underline{\ 2\ }\ Fe$

(j) $\underline{\quad}\ K_3PO_4 + \underline{\quad}\ Al(NO_3)_3 \rightarrow \underline{\ 3\ }\ KNO_3 + \underline{\quad}\ AlPO_4$

(k) $\underline{\ 2\ }\ NaI + \underline{\quad}\ Br_2 \rightarrow \underline{\ 2\ }\ NaBr + \underline{\quad}\ I_2$

BALANCING CHEMICAL EQUATIONS

Paper and Pencil Exercise

-- for the student --

Supply the coefficients which will balance the following:

(a) __ K + __ H_2O → __ KOH + __ H_2

(b) __ Fe + __ O_2 → __ Fe_2O_3

(c) __ $NaHCO_3$ → __ CO_2 + __ $NaOH$

(d) __ $Fe(OH)_3$ + __ HNO_3 → __ $Fe(NO_3)_3$ + H_2O

(e) __ Cu + __ H_2SO_4 → __ $CuSO_4$ + __ H_2

(f) __ C_2H_2 + __ O_2 → __ CO_2 + __ H_2O

(g) __ H_2O_2 → __ H_2O + __ O_2

(h) __ HgO → __ Hg + __ O_2

(i) __ Mg + __ $FeCl_3$ → __ $MgCl_2$ + __ Fe

(j) __ K_3PO_4 + __ $Al(NO_3)_3$ → __ KNO_3 + __ $AlPO_4$

(k) __ NaI + __ Br_2 → __ $NaBr$ + __ I_2

CHEMICAL EQUATIONS - SYNTHESIS

Paper and Pencil Exercise

-- for the teacher --

Synthesis or combination reactions are those in which two or more substances combine to form a single product. The reactants may be either elements or compounds, but the product is always a single compound.

I. Balance these examples of synthesis reactions by supplying the correct coefficients.

a) $\underline{\ 2\ }\ CO + \underline{\quad}\ O_2 \rightarrow \underline{\ 2\ }\ CO_2$

b) $\underline{\quad}\ CaO + \underline{\quad}\ H_2O \rightarrow \underline{\quad}\ Ca(OH)_2$

c) $\underline{\ 2\ }\ Mg + \underline{\quad}\ O_2 \rightarrow \underline{\ 2\ }\ MgO$

II. Supply the correct product (be sure to write the formula correctly) and then balance by adding coefficients.

a) $\underline{\quad}\ MgO + \underline{\quad}\ H_2O \rightarrow Mg(OH)_2$

b) $\underline{\ 4\ }\ Ag + \underline{\quad}\ O_2 \rightarrow 2\ Ag_2O$

c) $\underline{\ 2\ }\ Na + \underline{\quad}\ S \rightarrow Na_2S$

d) $\underline{\quad}\ C + \underline{\ 2\ }\ Cl_2 \rightarrow CCl_4$

e) $\underline{\ 2\ }\ Al + \underline{\ 3\ }\ I_2 \rightarrow 2\ AlI_3$

III. Write correct formulas to show the reactants and product in each of the following synthesis reactions. Then balance.

a) the reaction of sulfur trioxide and water to form sulfuric acid

$$SO_3 + H_2O \rightarrow H_2SO_4$$

b) the reaction of hydrogen and nitrogen to form ammonia (NH_3)

$$3H_2 + N_2 \rightarrow 2NH_3$$

c) the reaction when barium combines with oxygen

$$2Ba + O_2 \rightarrow 2BaO$$

CHEMICAL EQUATIONS - SYNTHESIS

Paper and Pencil Exercise

-- for the student --

Synthesis or combination reactions are those in which two or more substances combine to form a single product. The reactants may be either elements or compounds, but the product is always a single compound.

I. Balance these examples of synthesis reactions by supplying the correct coefficients.

a) $\_\_\ CO + \_\_\ O_2 \rightarrow \_\_\ CO_2$

b) $\_\_\ CaO + \_\_\ H_2O \rightarrow \_\_\ Ca(OH)_2$

c) $\_\_\ Mg + \_\_\ O_2 \rightarrow \_\_\ MgO$

II. Supply the correct product (be sure to write the formula correctly) and then balance by adding coefficients.

a) $\_\_\ MgO + \_\_\ H_2O \rightarrow$

b) $\_\_\ Ag + \_\_\ O_2 \rightarrow$

c) $\_\_\ Na + \_\_\ S \rightarrow$

d) $\_\_\ C + \_\_\ Cl_2 \rightarrow$

e) $\_\_\ Al + \_\_\ I_2 \rightarrow$

III. Write correct formulas to show the reactants and product in each of the following synthesis reactions. Then balance.

a) the reaction of sulfur trioxide and water to form sulfuric acid

b) the reaction of hydrogen and nitrogen to form annomia (NH_3)

c) the reaction when barium combines with oxygen

CHEMICAL EQUATIONS - ANALYSIS

Paper and Pencil Exercise

-- for the teacher --

Analysis or decomposition reactions are those in which a single compound breaks down into two or more simpler substances. The reactant is always a single compound while the products may be either elements or compounds.

I. Balance these examples of analysis reactions by supplying the correct coefficients.

a) $\underline{\ 2\ }\ KClO_3 \rightarrow \underline{\ 2\ }\ KCl + \underline{\ 3\ }\ O_2$

b) $\underline{\quad}\ CaCO_3 \rightarrow \underline{\quad}\ CaO + \underline{\quad}\ CO_2$

c) $\underline{\quad}\ NH_4OH \rightarrow \underline{\quad}\ NH_3 + \underline{\quad}\ H_2O$

II. Supply the correct products (be sure to write formulas correctly) and then balance by adding coefficients.

a) $\underline{\ 2\ }\ NaCl \rightarrow 2Na + Cl_2$

b) $\underline{\ 2\ }\ H_2O_2 \rightarrow 2H_2O + O_2$

c) $\underline{\quad}\ PbO_2 \rightarrow Pb + O_2$

III. Write correct formulas to show the reactant and the products in each of the following reactions. Then balance.

a) iron (III) hydroxide heated gives iron (III) oxide + water

$2Fe(OH)_3 \rightarrow Fe_2O_3 + 3H_2O$

b) bismuth carbonate heated gives bismuth oxide + carbon dioxide

$Bi_2(CO_3)_3 \rightarrow Bi_2O_3 + 3CO_2$

c) ammonium nitrate heated gives nitrogen (IV) oxide + water

$NH_4NO_3 \rightarrow N_2O + 2H_2O$

CHEMICAL EQUATIONS - ANALYSIS

Paper and Pencil Exercise
-- for the student --

Analysis or decomposition reactions are those in which a single compound breaks down into two or more simpler substances. The reactant is always a single compound while the products may be either elements or compounds.

I. Balance these examples of analysis reactions by supplying the correct coefficients.

a) ___ $KClO_3$ → ___ KCl + ___ O_2
b) ___ $CaCO_3$ → ___ CaO + ___ CO_2
c) ___ NH_4OH → ___ NH_3 + ___ H_2O

II. Supply the correct products (be sure to write formulas correctly) and then balance by adding coefficients.

a) ___ $NaCl$ →
b) ___ H_2O_2 →
c) ___ PbO_2 →

III. Write correct formulas to show the reactant and the products in each of the following reactions. Then balance.

a) iron (III) hydroxide heated gives iron (III) oxide + water

b) bismuth carbonate heated gives bismuth oxide + carbon dioxide

c) ammonium nitrate heated gives nitrogen (IV) oxide + water

CHEMICAL EQUATIONS - SINGLE REPLACEMENT

Paper and Pencil Exercise

-- for the teacher --

Single replacement reactions are those in which a free element replaces an element in a compound, forming a new compound and releasing the replaced element. Such reactions take place because a more active element is able to replace a less active element. Activity of the elements can be determined by consulting an Activity Series.

I. Balance these examples of single replacement reactions by supplying the correct coefficients.

a) $\_\_\_\ Zn + \underline{\ 2\ }\ HCl \rightarrow \_\_\_\ ZnCl_2 + \_\_\_\ H_2$

b) $\underline{\ 2\ }\ KBr + \_\_\_\ Cl_2 \rightarrow \underline{\ 2\ }\ KCl + \_\_\_\ Br_2$

c) $\underline{\ 2\ }\ Fe + \underline{\ 6\ }\ HC_2H_3O_2 \rightarrow \underline{\ 2\ }\ Fe(C_2H_3O_2)_3 + \underline{\ 3\ }\ H_2$

II. Supply the correct products (be sure to write formulas correctly) and then balance by adding coefficients.

a) $\underline{\ 2\ }\ Al + \underline{\ 3\ }\ Pb(NO_3)_2 \rightarrow 2\ Al(NO_3)_3 + \underline{\ 3\ }\ Pb$

b) $\underline{\ 3\ }\ Mg + \underline{\ 2\ }\ H_3PO_4 \rightarrow Mg_3(PO_4)_2 + 3H_2$

c) $\underline{\ 2\ }\ K + \underline{\ 2\ }\ HOH \rightarrow 2KOH + H_2$

d) $\_\_\ Cl_2 + \_\_\ CaI_2 \rightarrow CaCl_2 + I_2$

III. Write correct formulas to show reactants and products in each of the following reactions. Then balance.

a) sodium + water to produce sodium hydroxide + hydrogen

$2\ Na + 2H_2O \rightarrow 2NaOH + H_2$

b) aluminum + copper (II) sulfate gives aluminum sulfate + copper

$2Al + 3CuSO_4 \rightarrow Al_2(SO_4)_3 + 3Cu$

CHEMICAL EQUATIONS - SINGLE REPLACEMENT

Paper and Pencil Exercise
-- for the student --

Single replacement reactions are those in which a free element replaces an element in a compound, forming a new compound and releasing the replaced element. Such reactions take place because a more active element is able to replace a less active element. Activity of the elements can be determined by consulting an Activity Series.

I. Balance these examples of single replacement reactions by supplying the correct coefficients.

a) ___ Zn + ___ $HCl \rightarrow$ ___ $ZnCl_2$ + ___ H_2

b) ___ KBr + ___ $Cl_2 \rightarrow$ ___ KCl + ___ Br_2

c) ___ Fe + ___ $HC_2H_3O_2 \rightarrow$ ___ $Fe(C_2H_3O_2)_3$ + ___ H_2

II. Supply the correct products (be sure to write formulas correctly) and then balance by adding coefficients.

a) ___ Al + ___ $Pb(NO_3)_2 \rightarrow$

b) ___ Mg + ___ $H_3PO_4 \rightarrow$

c) ___ K + ___ $HOH \rightarrow$

d) ___ Cl_2 + ___ $CaI_2 \rightarrow$

III. Write correct formulas to show reactants and products in each of the following reactions. Then balance.

a) sodium + water to produce sodium hydroxide + hydrogen

b) aluminum + copper (II) sulfate gives aluminum sulfate + copper

CHEMICAL EQUATIONS - DOUBLE REPLACEMENT

Paper and Pencil Exercise

-- for the teacher --

Double replacement reactions are those in which a positive ion from one ionic compound exchanges with the positive ion of another ionic compound. These reactions are of little value unless they produce distinct products that can be separated. This occurs only when one of the products is one of the following: a) a precipitate (a solid settling out), b) a gas given off, or c) water.

I. Balance these examples of double replacement reactions by supplying the correct coefficients.

a) $\underline{\quad}\ Zn(NO_3)_2 + \underline{\quad}\ K_2CO_3 \rightarrow \underline{\quad}\ ZnCO_3 + \underline{\ 2\ }\ KNO_3$

b) $\underline{\quad}\ PbO_2 + \underline{\ 4\ }\ HNO_3 \rightarrow \underline{\quad}\ Pb(NO_3)_4 + \underline{\ 2\ }\ H_2O$

c) $\underline{\ 2\ }\ SbCl_3 + \underline{\ 3\ }\ H_2S \rightarrow \underline{\quad}\ Sb_2S_3 + 6HCl$

II. Supply the correct products (be sure to write formulas correctly) and then balance by adding coefficients.

a) $\underline{\quad}\ Li_2O + \underline{\ 2\ }\ HF \rightarrow 2LiF + H_2O$

b) $\underline{\ 3\ }\ Ba(OH)_2 + \underline{\ 2\ }\ H_3PO_4 \rightarrow Ba_3(PO_4)_2 + 6H_2O$

c) $\underline{\ 3\ }\ AgNO_3 + \underline{\quad}\ AlCl_3 \rightarrow 3\ AgCl + Al(NO_3)_3$

III. Write correct formulas to show reactants and products in each of the following reactions. Then balance.

a) sodium carbonate + sulfuric acid gives sodium sulfate + water + carbon dioxide

$Na_2CO_3 + H_2SO_4 \rightarrow Na_2SO_4 + H_2O + CO_2$

b) aluminum sulfate + calcium chloride gives calcium sulfate + aluminum chloride

$Al_2(SO_4)_3 + 3CaCl_2 \rightarrow 3CaSO_4 + 2AlCl_3$

CHEMICAL EQUATIONS - DOUBLE REPLACEMENT

Paper and Pencil Exercise

-- for the student --

Double replacement reactions are those in which a positive ion from one ionic compound exchanges with the positive ion of another ionic compound. These reactions are of little value unless they produce distinct products that can be separated. This occurs only when one of the products is one of the following: a) a precipitate (a solid settling out), b) a gas given off, or c) water.

I. Balance these examples of double replacement reactions by supplying the correct coefficients.

a) $\_\_\ Zn(NO_3)_2 + \_\_\ K_2CO_3 \rightarrow \_\_\ ZnCO_3 + \_\_\ KNO_3$

b) $\_\_\ PbO_2 + \_\_\ HNO_3 \rightarrow \_\_\ Pb(NO_3)_4 + \_\_\ H_2O$

c) $\_\_\ SbCl_3 + \_\_\ H_2S \rightarrow \_\_\ Sb_2S_3 + \_\_\ HCl$

II. Supply the correct products (be sure to write formulas correctly) and then balance by adding coefficients.

a) $\_\_\ Li_2O + \_\_\ HF \rightarrow$

b) $\_\_\ Ba(OH)_2 + \_\_\ H_3PO_4 \rightarrow$

c) $\_\_\ AgNO_3 + \_\_\ AlCl_3 \rightarrow$

III. Write correct formulas to show reactants and products in each of the following reactions. Then balance.

a) sodium carbonate + sulfuric acid

b) aluminum sulfate + calcium chloride

COMPLETING AND BALANCING CHEMICAL EQUATIONS

Paper and Pencil Exercise
-- for the teacher --

Supply the products and balance for each example of the types of equations below:

I. DIRECT COMBINATION (COMPOSITION)

a) $\underline{\ 2\ }\ Ba + \underline{\quad}\ O_2 \rightarrow 2BaO$

b) $\underline{\quad}\ H_2 + \underline{\quad}\ Cl_2 \rightarrow 2HCl$

c) $\underline{\ 3\ }\ Mg + \underline{\quad}\ N_2 \rightarrow Mg_3N_2$

II. DECOMPOSITION (ANALYSIS)

a) $\underline{\ 2\ }\ AlI_3 \rightarrow 2Al + 3I_2$

b) $\underline{\ 2\ }\ H_2O \rightarrow 2H_2 + O_2$

c) $\underline{\quad}\ MgCl_2 \rightarrow Mg + Cl_2$

III. SINGLE REPLACEMENT

a) $\underline{\ 3\ }\ Mg + \underline{\ 2\ }\ FeCl_3 \rightarrow 3MgCl_2 + 2Fe$

b) $\underline{\quad}\ Cl_2 + \underline{\ 2\ }\ NaBr \rightarrow 2NaCl + Br_2$

c) $\underline{\quad}\ Zn + \underline{\ 2\ }\ AgNO_3 \rightarrow Zn(NO_3)_2 + 2Ag$

IV. DOUBLE REPLACEMENT

a) $\underline{\quad}\ BaCl_2 + \underline{\quad}\ MgSO_4 \rightarrow BaSO_4 + MgCl_2$

b) $\underline{\quad}\ AgNO_3 + \underline{\quad}\ HCl \rightarrow AgCl + HNO_3$

c) $\underline{\quad}\ Na_2CO_3 + \underline{\quad}\ CaCl_2 \rightarrow CaCO_3 + 2NaCl$

COMPLETING AND BALANCING CHEMICAL EQUATIONS
Paper and Pencil Exercise
-- for the student --

Supply the products and balance for each example of the types of equations below:

I. DIRECT COMBINATION (COMPOSITION)

a) __ Ba + __ O_2 →
b) __ H_2 + __ Cl_2 →
c) __ Mg + __ N_2 →

II. DECOMPOSITION (ANALYSIS)

a) __ AlI_3 →
b) __ H_2O →
c) __ $MgCl_2$ →

III. SINGLE REPLACEMENT

a) __ Mg + __ $FeCl_3$ →
b) __ Cl_2 + __ NaBr →
c) __ Zn + __ $AgNO_3$ →

IV. DOUBLE REPLACEMENT

a) __ $BaCl_2$ + __ $MgSO_4$ →
b) __ $AgNO_3$ + __ HCl →
c) __ Na_2CO_3 + __ $CaCl_2$ →

DANCING SNOWBALLS

Demonstration

PURPOSE

The purpose of this demonstration is to stimulate a class discussion that centers on a student's power of observation. Hopefully, one of the observations will relate to the chemical reaction that is "powering" the "snowballs".

MATERIALS

Tall glass cylinder (1000 ml graduate or a gallon jar)
Moth balls (napthelene)
Sodium chloride
Marble chips (calcium carbonate)
HCl
Food coloring

PROCEDURE

1. Make a weak salt water solution and fill the cylinder.
2. Add five or six moth balls. If the moth balls float immediately, the salt solution is too strong. Dilute it. Add a few drops of food coloring to make the moth balls more visible.
3. Cover the bottom of the graduate with marble chips. Add 10 ml of 1M HCl. (If you have weaker acid readily available, use it - just use a little more.)

We suggest that you start this demonstration before school and have the demonstration on the desk when the class enters. The moth balls usually take about 15 minutes to start "doing their thing".

DISCUSSION

Ask the students:

1. Describe what you see happening?
2. Are all the moth balls moving at the same rate?
3. Do you think the liquid in the cylinder is water? Why or why not?
4. Do you think the mothballs will continue to go up and down indefinitely? Why or why not?
5. Why do the mothballs go up?
6. Why do they go down?

The observant student will notice the formation of bubbles at the bottom of the cylinder. When enough of these bubbles collect on the mothballs they will be less dense than the salt water and will float to the top where the bubbles are released - allowing the mothballs to sink and begin to collect bubbles again. The reaction will continue until the acid is used. You may start the reaction again by adding more acid.

The chemical reaction is:

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$$

This works in well near Christmas holidays and students may duplicate this at home using baking soda and vinegar in place of the marble chips and acid.

SELF PROPELLED SODIUM
Demonstration

PURPOSE

The purpose of this demonstration is to introduce a lesson on single replacement reactions.

MATERIALS

Petri dish, or a large flat clear glass container
Small lump of sodium
Phenolphthalein
Water
Overhead projector

PROCEDURE

1. Put about one inch of water in the clear dish on the overhead projector.
2. Add a few drops of phenolphthalein to show that the water itself does not cause a color change.
3. Cut a very small sized piece of sodium - almost too small to see on the knife.
4. Use forceps to add the sodium to the water.
5. Observe the movement of the sodium, the light, heat, and gas emitted. Note the color change.

DISCUSSION

Sodium replaces hydrogen in the water to produce sodium hydroxide and liberate hydrogen. The hydrogen gas occasionally ignites thus the flame seen. The sodium hydroxide is alkaline and causes the color change as it forms.

CAUTION: Sodium is stored in kerosene because it is very reactive in water. USE A SMALL PIECE! DO NOT TOUCH IT WITH YOUR HAND. The advantage of the overhead projector for student viewing of this demonstration is obvious.

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

ALUMINUM TO COPPER?

Demonstration

PURPOSE

The purpose of this demonstration is to introduce the concept of the activity series in single replacement reactions.

MATERIALS

100 ml beaker
Aluminum foil
Copper chloride

PROCEDURE

1. Put 50 ml of 1M $CuCl_2$ in the beaker.
2. Drop in a large crumpled ball of aluminum foil.
3. Ask the students to describe the reaction.

DISCUSSION

Observations might include: the blue solution changes to clear, a reddish-brown substance forms over the aluminum, hydrogen gas is produced.

Aluminum must be more active than copper to replace copper from the copper chloride.

ACTIVITY SERIES OF METALS

Lithium
Potassium
Barium
Calcium
Sodium
Magnesium
Aluminum
Zinc
Iron
Nickel
Tin
Lead
(Hydrogen)
Copper
Mercury
Silver
Gold

The top five metals will replace hydrogen from water as well as acids. Magnesium through lead will replace hydrogen from acids only. Metals will replace those metals below them on the chart.

TYPES OF CHEMICAL REACTIONS

Laboratory Exercise

--for the teacher--

PURPOSE

The purpose of this activity is to observe chemical reactions, classify the type of reaction, and to write a balanced equation for each reaction.

MATERIALS

Test tubes
Bunsen burner
Ring stand
Buret clamp
Wood splints
*Solutions of $CuSO_4$, $AlCl_3$ and NH_4OH
Litmus paper
Sodium bicarbonate
Calcium oxide
Zinc strip
Calcium turnings**

* You may wish to use 0.1M solutions of each of these.

** Very small calcium turnings are preferred. Calcium is very active and much heat is liberated.

PRELABORATORY DISCUSSION

It is important for students to realize that a chemical equation is not a statement of equality but a statement of process. The reactants on the left go through changes to produce the new products on the right. Of course, the number of atoms of each element is the same on each side. Through laboratory activities and demonstrations it is hoped that the student will understand this fundamental principle. This lab is more effective if it is done after students are familiar with the characteristics of oxygen, hydrogen, and carbon dioxide so that they can identify these gases.

PROCEDURE

1. Put 5 grams of sodium bicarbonate in a test tube. Heat the sample with the test tube in a horizontal position. Insert moistened pieces of red and blue litmus into the upper part of the test tube. Insert a flaming splint into the upper part of the test tube. Note any deposit on the sides of the test tube. Record your observations on the data table.
2. Test one gram of fresh, dry calcium oxide with red and blue litmus paper. Place the calcium oxide in a test tube, add 10 ml of water and shake for 2 minutes. Test again with litmus. Record observations on data table.
3. Put 5 ml of copper (II) sulfate solution in a test tube. Drop a clean Zn strip into the solution. Leave for 10 minutes. Examine the zinc strip and note any change. Record on the data table.
4. Add 5 ml of water to a test tube. Drop a clean calcium turning into the water. Immediately bring a flaming splint to the mouth of the test tube. Insert pieces of red and blue litmus paper into the resultant solution. Record your observations on the data table.
5. **To 5 ml of aluminum chloride solution add one ml of ammonium hydroxide solution. Record your observation on the data table.

**In procedure 5 you may wish to explain the use of a solubility chart to determine the name of the precipitate. The two products are ammonium chloride (which is soluble) and aluminum hydroxide (which is insoluble) so the white precipitant is $Al(OH)_3$.

DATA AND OBSERVATIONS

The following data table is to be used with all procedures in this lab.

PROCEDURE	REACTANT(S)	PRODUCT(S)	DESCRIBE OBSERVATION
1	sodium bicarbonate	carbon dioxide; sodium hydroxide	colorless gas puts out flame; base turns litmus paper blue
2.	calcium oxide and water	calcium hydroxide	turns litmus paper blue
3.	copper sulfate soln. zinc	copper; zinc sulfate	reddish coating on zinc strip; residue
4.	calcium water	calcium hydroxide; hydrogen	turns litmus paper blue; colorless gas, pops
5.	ammonium hydroxid aluminum chloride	ammonium chloride aluminum hydroxide	formation of a white precipate

CONCLUSIONS

Write a balanced chemical equation for each reaction:

1. $NaHCO_3 \rightarrow NaOH + CO_2$
2. $CaO + H_2O \rightarrow Ca(OH)_2$
3. $CuSO_4 + Zn \rightarrow ZnSO_4 + Cu$
4. $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$
5. $AlCl_3 + 3NH_4OH \rightarrow Al(OH)_3 + 3NH_4Cl$

Tell the type of chemical reaction for each procedure (synthesis, analysis, single replacement, double replacement).

1. Analysis (Decomposition)
2. Synthesis (Combination)
3. Single Replacement
4. Single Replacement
5. Double Replacement

TYPES OF CHEMICAL REACTIONS

Laboratory Exercise
-- for the student --

PURPOSE

The purpose of this activity is to observe chemical reactions, classify the type of reaction, and to write a balanced equation for each reaction.

MATERIALS

Test tubes Litmus paper
Bunsen burner
Ring stand
Buret clamp
Wood splints
Solutions of $CuSO_4$, $AlCl_3$ and NH_4OH
Sodium bicarbonate
Calcium oxide
Zinc strip
Calcium turnings

PROCEDURE

1. Put 5 grams of sodium bicarbonate in a test tube. Heat the sample with the test tube in a horizontal position. Insert moistened pieces of red and blue litmus into the upper part of the test tube. Insert a flaming splint into the upper part of the test tube. Note any deposit on the sides of the test tube. Record your observations on the data table.
2. Test one gram of fresh, dry calcium oxide with red and blue litmus paper. Place the calcium oxide in a test tube, add 10 ml of water and shake for 2 minutes. Test again with litmus. Record observations on data table.
3. Put 5 ml of copper (II) sulfate solution in a test tube. Drop a clean Zn strip into the solution. Leave for 10 minutes. Examine the zinc strip and note any change. Record on the data table.
4. Add 5 ml of water to a test tube. Drop a clean calcium turning into the water. Immediately bring a flaming splint to the mouth of the test tube. Insert pieces of red and blue litmus paper into the resultant solution. Record your observations on the data table.
5. To 5ml of aluminum chloride solution add one ml of ammonium hydroxide solution. Record your observation on the data table.

DATA AND OBSERVATIONS

The following data table is to be used with all procedures in this lab.

PROCEDURE	REACTANT(S)	PRODUCT(S)	DESCRIBE OBSERVATION
1.			
2.			
3.			
4.			
5.			

CONCLUSIONS

Write a balanced chemical equation for each reaction:

1.

2.

3.

4.

5.

Tell the type of chemical reaction for each procedure (synthesis, analysis, single replacement, double replacement).

1.

2.

3.

4.

5.

DO I SEE SPOTS?

Laboratory Exercise

-- for the teacher --

PURPOSE

The purpose of this activity is to recognize the formation of new compounds by ion exchange.

PRELABORATORY DISCUSSION

The formation of colored precipitates from colorless solutions is always an eye-catching reaction to chemistry students. The concept that rearranging a few atoms produces an entirely new substance with its own unique properties needs much reinforcement at this stage in chemistry. This lab is easy to set up, clean up, and "grade". Much of the success of the lab depends on the student following instructions, and thinking through the questions about his/her observations.

MATERIALS

* Five unknowns in dropper bottles

** Sheet of mimeograph paper marked off in a 5 by 5 square grid

* Suggested numerical order of unknowns:
Bottle 1 - sodium iodide.
Bottle 2 - mercury (II) chloride
Bottle 3 - silver nitrate
Bottle 4 - sodium chloride
Bottle 5 - lead (II) nitrate
(1.0 M solutions of all of these)

It is strongly recommended that dropper bottles be used for this lab. It simplifies the distribution of materials, it limits the amount of chemicals used, and gives the results on a single piece of paper for easy reference.

It is necessary to demonstrate the proper use of a medicine dropper or pipette. I have observed many students placing the tip of the dropper in contact with the previous drop on several occasions.

** Running off a prepared grid sheet with large squares (1 1/2 inch squares) for each lab group will simplify lab instructions. No harm is done if students "slant" the paper to run all the drops together when they have finished.

PROCEDURE

Locate horizontal row 1 on your grid sheet. Put one drop of unknown 1 in each of the 5 squares of horizontal row 1. Then locate vertical column one. Put unknown 1 in each of the squares in column one. Similarly add a drop of unknown 2 in each of the five horizontal and five vertical number 2 squares on the grid. Continue with the remaining unknowns (3, 4, 5). Each square now contains a mixture of two drops.

OBSERVATIONS

In the grid below write in the colors of the precipitates.

	1	2	3	4	5
1		orange red	light yellow		deep yellow
2	orange red		violet		white
3	light yellow	violet		violet	
4			violet		white
5	deep yellow	white		white	

Identifying colors of some possible compounds formed:

white	$PbCl_2$	lead chloride
light yellow	AgI	silver iodide
orange-red	HgI_2	mercury iodide
deep yellow	PbI_2	lead iodide
*white-turning violet in light	AgCl	silver chloride

*works best in sunlight

Add to the grid the names of compounds to match the colors.

QUESTIONS:

1. In which squares did a deep yellow compound form? 1-5, 5-1 What is its formula? PbI_2
2. Looking further in the same column with the deep yellow spot, what other colored spots formed? orange-red, light yellow. In what squares? orange-red in 1-2; and light yellow in 1-3

   What are these formulas? HgI_2 and AgI
3. What ion do the spots in this column have in common? I^-
4. Study the horizontal rows and vertical columns on the grid. What metal ions do these colored precipates have in common? Column 5 has two spots that contain Pb.
5. Continue for all columns. Can you determine the unknown ion in each column?

The unknown compounds (not in the order numbered) are:

$AgNO_3$ NaCl $HgCl_2$ NaI $Pb(NO_3)_2$

CONCLUSIONS

1. List the unknowns in bottles 1 through 5.

Bottle 1	sodium iodide	Bottle 2	mercury (II) chloride
Bottle 3	silver nitrate	Bottle 4	sodium chloride
Bottle 5	lead (II) nitrate		

2. In what squares did you anticipate that no colors would form? 1-1, 2-2, 3-3, 4-4, 5-5 because these squares contained two drops of the same compound. Also, those squares in which the two compounds had a common ion such as sodium iodide and sodium chloride.

DO I SEE SPOTS?

Laboratory Exercise
-- for the student --

PURPOSE

The purpose of this activity is to recognize the formation of new compounds by ion exchange.

MATERIALS

Five unknowns in dropper bottles
Sheet of mimeograph paper marked off in a 5 by 5 square grid

PROCEDURE

Locate horizontal row 1 on your grid sheet. Put one drop of unknown 1 in each of the 5 squares of horizontal row 1. Then locate vertical column one. Put unknown 1 in each of the squares in column one. Similarly add a drop of unknown 2 in each of the five horizontal and five vertical number 2 squares on the grid. Continue with the remaining unknowns (3, 4, 5). Each square now contains a mixture of two drops

OBSERVATIONS

In the grid below write in the colors of the precipitates.

	1	2	3	4	5
1					
2					
3					
4					
5					

Identifying colors of some possible compounds formed:

COLOR	FORMULA	NAME
white	$PbCl_2$	lead chloride
light yellow	AgI	silver iodide
orange-red	HgI_2	mercury iodide
deep yellow	PbI_2	lead iodide
*white-turning violet in light	AgCl	silver chloride

Add to the grid the names of compounds to match the colors.

QUESTIONS:

1. In which squares did a deep yellow compound form? ________ What is its formula? ________________
2. Looking further in the column with the deep yellow spot, what other colored spots formed? ______________________________
   In what squares? _________________________
   What are these formulas? ____________________
3. What ion do the spots in this column have in common? __________
4. Look at another horizontal and vertical row. What ion do these colored spots have in common? _____________________________
5. Continue for all columns. Can you determine the unknown ion in each column?

The unknown compounds (not in the order numbered) are:

$AgNO_3$ NaCl $HgCl_2$ NaI $Pb(NO_3)_2$

CONCLUSIONS

1. List the unknowns in bottles 1 through 5.

   Bottle 1 Bottle 2
   Bottle 3 Bottle 4
   Bottle 5
2. In what squares did you anticipate that no colors would form?
   ______________________________ Explain why. ______________________________
   ____

DETERMINING EMPIRICAL FORMULAS

Laboratory Exercise
-- for the teacher --

PURPOSE

This laboratory exercise illustrates a simple method to determine the formula of a compound. With the use of paper clips, students can visualize how atoms combine in fixed ratios and how these ratios are determined by finding the mass of each atom (paper clips in these activities) . Large and small paper clips provide useful and concrete images of how atoms combine and exist in nature, which unfortunately we cannot observe directly. In addition, large and small paper clips are easy to obtain and to work with.

MATERIALS

Box of large paper clips
Box of small paper clips (these are the regular size clips)
A laboratory balance

This laboratory exercise can also be done with nuts and bolts.

PROCEDURE

In advance of the laboratory activity ask a few students to pair up the paper clips, combining one large clip with one small clip by hooking the pair together. The idea here is to be sure that each laboratory group of students has an equal number of large and small paper clips.

1. Begin the lab by telling the students **not** to count the paper clips because we are going to let a paper clip represent an atom, and we cannot count atoms.
2. Form pairs of students or small groups of students to work together.
3. Give each group of students a small handful of paper clips. It does not matter that each group has a different number of clips. However, the accuracy of the ratio that is expected will improve as the number of clips increases.
4. Instruct students to take apart the paper clips, placing the large clips in one pile and the small clips in another pile.
5. Weigh the pile of large clips and record the mass. Weigh the pile of small clips and record the mass.
6. From the data collected in step 5, and without counting the clips or weighing them individually, calculate the ratio of the weight of one large clip to one small clip.
7. From your answer in step 6, and without counting in any way, predict the weight in grams of large clips that would be necessary to pair up one-for-one with 10 grams of small clips. Weigh out this amount of large clips.
8. Weigh out 10 grams of small clips.
9. See if your weighed amount of large clips will pair up evenly with the 10 grams of small clips.
10. If the clips did not pair up evenly (within + 1 clip) recalculate step 6 and repeat steps 7, 8, and 9.

DATA AND OBSERVATIONS

This is what our data looked like:

weight of pile of small clips 6.8 grams
weight of equal number of large clips 20.5 grams
ratio of weight of large to small clips 3 to 1

QUESTIONS

1. What weight of large clips would be necessary to pair up one for one with 16.7 grams of small clips? 50 grams

2. What weight of large clips would be necessary to contain the same number of clips as 100 tons of small clips? 300 tons
3. What weight of small clips would be necessary to have enough to clip two of them to each large clip if you had 72 grams of large clips?
   48 grams
4. If you had a "compound" made of large clips and small clips but you did not know the ratio of each, could you find the ratio if you knew the masses of large clips and small clips separately? Hopefully, yes.
   If the large clips weighed a total of 300 grams and the small clips also weighed 300 grams, what would the ratio of large to small be in that "compound"? 1 large to 3 small

Large	Small
3 : 300 g	1 : 300 g
100	300
Express as a ratio: 1:3	

5. The ratio of the mass of carbon to hydrogen is 12:1. A compound of carbon and hydrogen is broken down to yield 60 grams of carbon and 20 grams of hydrogen. What is the formula for this hydrocarbon? CH_4

Carbon	Hydrogen
12 : 60 g	1 : 20 g
5	20
Express as a ratio: 1:4	

DETERMINING EMPIRICAL FORMULAS

Laboratory Exercise

-- for the student --

PURPOSE

The purpose of this activity is to illustrate how the empirical formula for a compound may be determined experimentally.

MATERIALS

Paper clips (already paired)
Balance

PROCEDURE

1. Take apart the paper clips and put the large paper clips in one pile and the small paper clips in another.
2. Weigh the pile of large paper clips and record the weight. Weigh the pile of small paper clips and record the weight.
3. From the data collected in step 2 and without counting the clips or weighing them individually, calculate the ratio of the weight of one large clip to one small clip.
4. From your answer in step 3, and without counting in any way, predict the weight in grams of large clips that would be necessary to pair up one for one with 10 grams of small clips. Weigh out this amount of large clips.
5. Weigh out 10 grams of small clips.
6. See if your weighed amount of large clips will pair up evenly with the 10 grams of small clips.
7. If the clips did not pair up evenly (within + 1 clip) recalculate step 6 and repeat steps 5 and 6.

DATA AND OBSERVATIONS

Weight of pile of small clips ________________

Weight of equal number of large clips ______________

Ratio of weight of large to small clips _______________

QUESTIONS

1. What weight of large clips would be necessary to pair up one for one with 16.7 grams of small clips? ________________________
2. What weight of large clips would be necessary to contain the same number of clips as 100 tons of small clips? ____________________
3. What weight of small clips would be necessary to have enough to clip two of them to each large clip if you had 72 grams of large clips? ________________________
4. If you had a "compound" made of large clips and small clips but you did not know the ratio of each, could you find the ratio if you knew the masses of large clips and small clips separately?

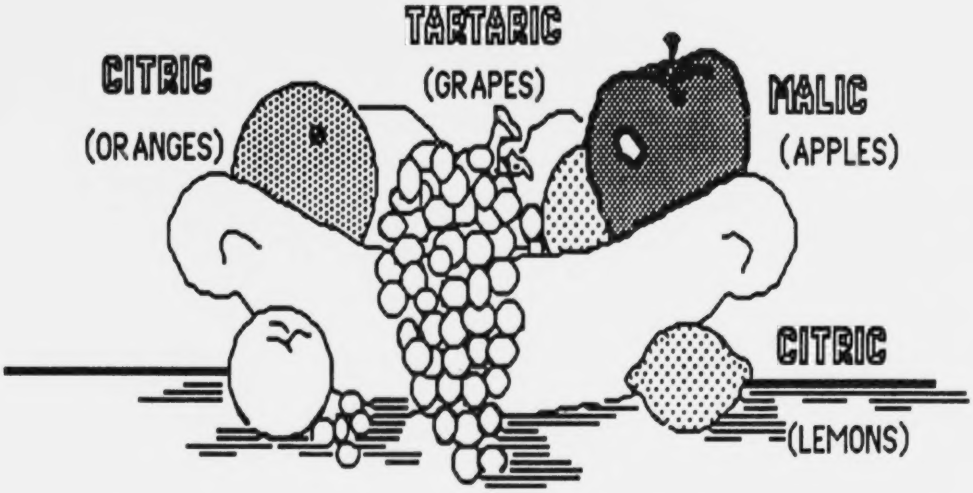
   ____

   If the large clips weighed a total of 300 grams and the small clips also weighed 300 grams, what would the ratio of large to small be in that "compound"? ________________
5. The ratio of the mass of carbon to hydrogen is 12:1. A compound of carbon and hydrogen is broken down to yield 60 grams of carbon and 20 grams of hydrogen. What is the formula for this hydrocarbon? ______

Acids and Bases

Background Information

6



Most physical science teachers begin their study of chemistry by classifying matter. Matter is generally divided into three classes or groups -- **elements, compounds, and mixtures.** For convenience in studying compounds, they are also divided into classes or groups based on their composition or properties. Two of these classes are acids and bases.

ACIDS

Acids play an important role in our everyday lives and in industry. Many of our foods contain acids. Citric acid is found in citrus fruits; buttermilk contains lactic acid; vinegar contains acetic acid; tartaric acid is found in grapes and malic acid is found in apples. Ascorbic acid is vitamin C, and proteins are made up of amino acids. Hydrochloric acid, along with the gastric juice in the stomach, breaks down food during digestion.

Sulfuric acid, nitric acid, and hydrochloric acid are manufactured by thousands of tons. They are used extensively in industry. They are used in producing metals, plastics, explosives, textiles, dyes, fertilizers, drugs and other chemicals. Acetic acid is used commercially as a solvent and in making rayon and photographic film. From these examples, you can see why acids are such important compounds. In Table #1, below, you will find a list of some of the common acids, their chemical formulas, and common names (where available).

Table 1. Common Acids

Acid	Formula	Common Name
Hydrochloric	HCl	Muriatic acid
Nitric	HNO_3	Aqua fortis
Sulfuric	H_2SO_4	Oil of Vitriol
Acetic	$HC_2H_3O_2$	Vinegar
Carbonic	H_2CO_3	Carbonated water
Boric	H_3BO_3	Boric acid
Citric	$H_3C_6H_5O_7$	Lemon juice

As mentioned earlier, the term "acid" refers to a group of organic and inorganic chemical compounds with common properties. The acids studied in the physical science class are mostly inorganic acids. The inorganic acids include sulfuric acid (H_2SO_4), hydrochloric acid (HCl), nitric acid (HNO_3), and phosphoric acid (H_3PO_4). Organic acids contain carbon atoms. Carboxylic acids are the most common type of organic acids. They contain a characteristic group of atoms called the carboxyl group (--COOH). Formic acid (HCOOH), acetic acid (CH_3COOH), and butyric acid (C_3H_7COOH) are examples of carboxylic acids.

The properties common to acids are:

1. Water solutions of acids taste sour. Although many acids are harmless and may be taken into the body in the form of food, many acids are also deadly poisons and have a burning, corrosive action. As a general rule, chemicals in the laboratory should never be tasted.
2. Acid compounds can be identified by using substances known as indicators. One such indicator is called **litmus paper.** Litmus paper consists of small strips of paper stained with a dye obtained from plants called lichens. An acid solution will cause blue litmus paper to turn red. Red litmus paper will retain its color in an acid solution.
3. Many acids will react with active metals such as zinc, magnesium, and iron to form bubbles of hydrogen gas. During the reaction, the metal liberates or frees the hydrogen from the acid and combines with the remaining ion to form a metal salt in the solution.
4. When an acid and a base are mixed together in the proper proportions, they neutralize each other. In the reaction, the hydrogen from the acid combines with the hydroxide from the base to form water. The positive ion from the base combines with the negative ion from the acid to form a salt. The products of a **neutralization reaction** are always water and a salt.
5. Acids ionize when dissolved in water. Since acids ionize, they have the ability to conduct an electric current. Acids do not ionize to the same degree. Strong acids ionize more completely than weak acids. For example, hydrochloric acid will ionize almost completely in water. A solution of a weak acid, such as acetic acid, forms fewer ions in water solution.
6. Water solutions of all acids contain **hydrogen ions.** The hydrogen ions combine with the atoms of the water molecules (H_2O) to form hydonium (H_3O^+) ions. The presence of hydrogen ions is considered to be the cause of the sour taste and other properties common to all acids.

BASES

You will probably use several bases before the day is over. Many household cleaning products contain bases. Bases are used to counteract (neutralize) acids in the stomach. Bases are used extensively in the refining of petroleum and in the manufacture of rayon, soap, paper, and many other products. In Table 2, some common bases and their uses are listed.

Table 2. Commom Bases

Base	Formula	Common Name	Important Uses
Sodium hydroxide	$NaOH$	Lye or caustic soda	Production of rayon and soap
Potassium hydroxide	KOH	Caustic potash	Manufacture of soft soap and special glass
Magnesium hydroxide	$Mg(OH)_2$	Milk of magnesia	To counteract stomach acidity
Calcium hydroxide	$Ca(OH)_2$	Slaked lime	To make mortar
Aluminum hydroxide	$Al(OH)_3$		Purification of water and to set dye
Ammonium hydroxide	NH_4OH	Ammonia water	Household cleanser

The class of compounds known as bases has some properties which are the same as those of acids. But most of the properties of bases are different from the properties of acids and, in many cases, the opposite of the properties of acids. Following is a list of properties common to bases:

1. Bases, when mixed with water, have the ability to conduct electricity. This is due to the ability of bases to ionize. Like acids, a weak base such as magnesium hydroxide or iron II or III hydroxide will not ionize completely, whereas a strong base such as calcium hydroxide or sodium hydroxide will ionize completely in water.
2. Water solutions of bases taste bitter and feel slippery. CAUTION; DO NOT TASTE LABORATORY CHEMICALS AND ALWAYS HANDLE CHEMICALS WITH PRECAUTION.
3. Bases turn red litmus paper blue, methyl orange turns yellow, and phenolphthalein turns bright pink or red.
4. Bases emulsify fats and oils, that is, they have the ability to break down oil or fat into very small droplets. As the oils and fats are removed from the surface to which they are stuck, they become dispersed throughout the emulsifying agent.
5. Bases neutralize the effect of acids.
6. Strong water solutions of bases are caustic (capable of destroying or eating away).
7. Bases have common properties because all bases contain a common ion. They all contain **hydroxide ions.** A hydroxide ion consists of an oxygen atom and a hydrogen atom. The hydrogen component has a charge of **+1** and the oxygen a **-2** leaving the hydroxide ion with a negative electrical charge (**-1**).

THE pH SCALE, A MEASURE OF HYDROGEN ION CONCENTRATION

Water and all water solutions contain both **hydrogen** and **hydroxide ions.** Recall, it is the concentration (or relative amounts) of these ions that determine the strength of an acid or a base. Chemists and biologists use a scale called the **pH scale** to express the relative strength of acids and bases. Numerically, the common pH values fall within the range of 0 to 14 on the scale. The pH is officially defined by the expression

$$pH = -\log_{10}[H^+]$$

The pH values for the acid and base solutions we have been dealing with are easily obtained from the hydrogen ion concentration. For example: if a solution contains 0.01 M HCl (100 percent ionized), we write

$$[H^+] = 0.01\ M = 10^{-2}\ M.$$

Now that the hydrogen ion concentration has been expressed in this exponential form (10^{-2}), the pH value is obtained by simply taking the exponent of 10 (-2, in this case) and changing its sign:

$$pH = 2$$

In pure water, the concentration of hydrogen ions is completely balanced by the concentration of hydroxide ions. Water is chemically neutral. Thus, its pH value is located in the center of the scale; water has a pH of 7.0. A pH value less than 7.0 is acidic and a pH value greater than 7.0 is basic. Notice, a decrease in hydrogen ion concentration is represented by a numerical increase on the pH scale.

THE pH SCALE

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Acidic (0–7) | Neutral (7) | Basic (7–14)

Table 3. Approximate pH Values Of Some Common Substances In Dilute Solutions

Substance	Formula	pH
Hydrochloric acid	HCl	1.0
Acetic acid	$HC_2H_3O_2$	2.9
Boric acid	H_3BO_3	5.1
Pure water	H_2O	7.0
Bicarbonate of soda	$NaHCO_3$	8.4
Ammonia water	NH_4OH	11.1
Washing soda	Na_2CO_3	11.3
Lye	$NaOH$	13.0

SOME COMMON ACIDS AND THEIR USES

Hydrochloric:	preparation and purification of metals, used in medicine (normallly found in the gastric juices and is necessary for the proper digestion of proteins in the stomach), and used as a bleaching agent.
Sulfuric:	important in the production of fertilizers, paint, plastics, gasoline, and steel; very important to industry; used in preparation of other acids in the laboratory; used in automobile batteries; and serves as a dehydrating agent.
Nitric:	used in the laboratory to test for the presence of proteins.
Phosphoric:	used in industry in the preparation of inorganic phosphate compounds, used in fertilizers, soft drinks, and flavoring syrups; the salt -- sodium phosphate -- is an excellent water softener.
Boric:	used as an antiseptic and a germicide (eyewash).
Acetylsalicylic:	pain killer (aspirin).
Ascorbic:	used in prevention and treatment of scurvy, it is vitamin C.
Lactic:	the acid found in milk.
Acetic:	the acid found in vinegar.

SOME COMMON BASES AND THEIR USES

Sodium hydroxide:	used in industry and in laboratories; used to remove fats and grease from clogged drains; and to make soap.
Magnesium hydroxide:	milk of magnesia, used as an antacid and as an antidote for acid poisoning, used in laxatives.
Ammonium hydroxide:	known as ammonia water, used as a cleaning agent.
Aluminum hydroxide:	used in deodorants.
Calcium hydroxide:	used in the manufacture of mortar and plaster, and used as a dehairing agent for hides.
Potassium hydroxide:	used in making soft soaps that dissolve easily in water.

ACIDS AND BASES

Paper and Pencil Exercise

-- for the teacher --

I. PROPERTIES OF ACIDS AND BASES

Identify each of the following properties as being characteristic of an acid or a base. Write the word acid and/or base in the space provided. Remember, some may be properties of both acids and bases.

a. acid turns litmus red.

b. acid reacts with metals to produce hydrogen gas.

c. base turns phenolphthalein pink.

d. acid contains hydrogen ions.

e. base feels slippery.

f. acid and base conduct electrical current.

g. acid and base ionize to form ions.

h. base tastes bitter or flat.

In the following list, underline the examples that demonstrate characteristics of acids.

a. Lemon juice tastes sour.

b. Vinegar turns blue litmus paper red.

c. Ammonia turns red litmus paper blue.

d. Orange juice turns blue litmus paper red.

e. Sugar tastes sweet.

f. Salt tastes salty.

g. Vinegar tastes sour.

In the following list, underline the examples that demonstrate characteristics of bases.

a. Lemon juice turns blue litmus paper red.

b. Ammonia turns red litmus paper blue.

c. Baking soda changes the color of phenolphthalein to pink.

d. Vitamin C tastes sour.

e. An unknown solution turns red litmus paper blue.

f. Shampoo tastes bitter.

II. THINKING ABOUT ACIDS AND BASES

Why is sodium hydroxide, NaOH, considered a strong base and magnesium hydroxide, $Mg(OH)_2$, a weak base?

Answer -- Sodium hydroxide will ionize almost completely. Magnesium hydroxide will not ionize completely, therefore it is weak.

How is the strength of an acid or base expressed using the pH scale?

Answer -- The pH scale is a numerical scale that expresses hydrogen ion concentration. A pH value of 7.0 is neutral -- the number of hydrogen ions equals the number of hydroxide ions; a pH less than 7.0 is acidic and a pH more than 7.0 is basic. As the hydrogen ion concentration increases the pH value decreases.

What is a neutralization reaction?

Answer -- A reaction between an acid and a base to produce a salt and water.

Complete the following chemical equations.

Answer --

$$NaOH + HCl \dashrightarrow \underline{NaCl} + \underline{HOH}$$

$$H_2SO_4 + Ca(OH)_2 \dashrightarrow \underline{CaSO_4} + \underline{2\,HOH}$$

ACIDS AND BASES
Paper and Pencil Exercise
-- *for the student* --

I. PROPERTIES OF ACIDS AND BASES

Identify each of the following properties as being characteristic of an acid or a base. Write the word acid and/or base in the space provided. Remember, some may be properties of both acids and bases.

a. ______________________ turns litmus red.

b. ______________________ reacts with metals to produce hydrogen gas.

c. ______________________ turns phenolphthalein pink.

d. ______________________ contains hydrogen ions.

e. ______________________ feels slippery.

f. ______________________ conduct electrical current.

g. ______________________ ionize to form ions.

h. ______________________ tastes bitter or flat

In the following list, underline the examples that demonstrate characteristics of acids.

a. Lemon juice tastes sour.

b. Vinegar turns blue litmus paper red.

c. Ammonia turns red litmus paper blue.

d. Orange juice turns blue litmus paper red.

e. Sugar tastes sweet.

f. Salt tastes salty.

g. Vinegar tastes sour.

In the following list, underline the examples that demonstrate characteristics of bases.

a. Lemon juice turns blue litmus paper red.

b. Ammonia turns red litmus paper blue.

c. Baking soda changes the color of phenolphthalein to pink.

d. Vitamin C tastes sour.

e. An unknown solution turns red litmus paper blue.

f. Shampoo tastes bitter.

II. THINKING ABOUT ACIDS AND BASES

Why is sodium hydroxide, NaOH, considered a strong base and magnesium hydroxide, $Mg(OH)_2$, a weak base?

How is the strength of an acid or base expressed using the pH scale?

What is a neutralization reaction?

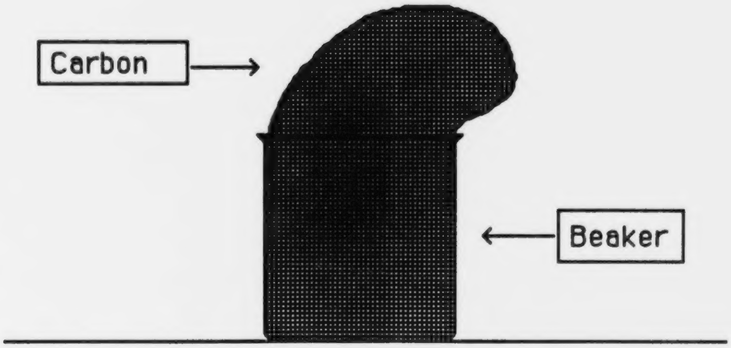
Complete the following chemical equations.

$NaOH + HCl \rightarrow$ ______ + ______

$H_2SO_4 + Ca(OH)_2 \rightarrow$ ______ + ______

CARBON IN SUGAR?

Demonstration



PURPOSE

The purpose of this demonstration is to show the dehydrating effect of sulfuric acid. It can also be used to introduce a unit or lesson on acids. This demonstration has never failed to amaze students.

MATERIALS

100 ml beaker
Granulated sugar
Concentrated sulfuric acid
Glass stirring rod

PROCEDURE

1. Fill a small beaker half full of sugar.

2.* Pour in enough concentrated sulfuric acid to wet the sugar thoroughly. Stir the sugar with a glass rod as you pour in the acid.

3. Wait and watch -- the results will be **spectacular.** Your students will be amazed as they watch the white sugar first turn yellow, then brown, and finally black as it smokes, expands and rises out of the beaker.

*This should be done under a hood. If a hood is not available, be sure to keep the quantities small and the room well ventilated or carry out the procedures near a window. **Use goggles to conduct this demonstration.**

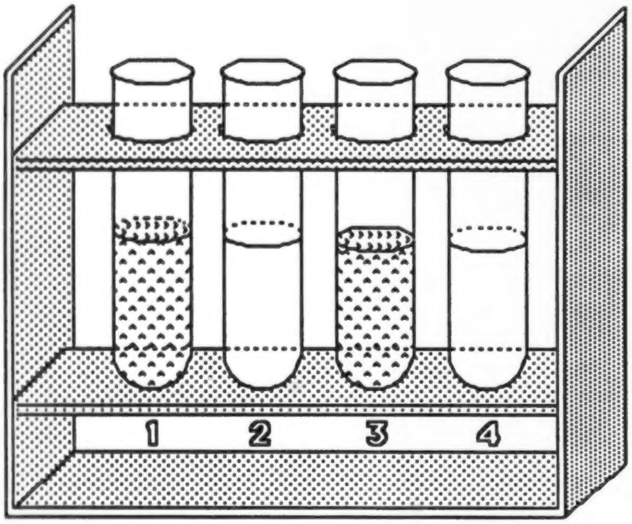
DISCUSSION

The sulfuric acid dehydrates the sugar, taking out the water and leaving elementary carbon. When it cools, the beaker with its spongy mass of carbon can be passed around the class. Students should not touch it with the hands since acid is present. Don't worry, clean up is very simple. Just remove the carbon and add water to the beaker. The residue will wash out with a little brushing.

The chemical formula for sucrose is $C_{12}H_{22}O_{11}$. The empirical formula is CH_2O, or hydrate of carbon $C \cdot H_2O$.

MAGIC OR CHEMISTRY?

Demonstration



PURPOSE

The purpose of this demonstration is to introduce students to indicators, arousing curiosity and achieving a high degree of interest.

MATERIALS

Test tube rack
4 test tubes labeled #1, #2, #3, and #4
Opaque beaker or small container
Phenolphthalein indicator
Hydrochloric acid (dilute)
Sodium hydroxide (dilute)

PROCEDURE I: BEFORE CLASS PREPARATIONS

1. Place four test tubes in a test tube rack and label them #1, #2, #3, and #4.
2. Put a drop of phenolphthalein in test tubes #1 and #3; leave test tube #2 empty.
3. Put a few drops of acid in test tube #4.
4. Put a few drops of base in the beaker. All of the test tubes and the beaker should appear to be empty. Put all chemicals out of sight.

You will need to experiment and **practice** beforehand to determine the number of drops of acid, base, and phenolphthalein to use to obtain the desired results (See Procedure II: THE MAGIC TRICK).

PROCEDURE II: THE MAGIC TRICK

1. Begin the magic trick by filling the beaker with tap water.
2. Fill test tubes #1, #2, and #3 from the beaker. Leave #4 empty.
3. Call attention to the fact that tubes #1 and #3 are bright pink while #2 is colorless. **"Something must be wrong, let me try again."**

4. Pour the contents of all three test tubes back into the beaker, and fill all four test tubes this time. Call attention to the fact that test tubes #1, #2, and #3 are bright pink but #4 is colorless. **"Uh-oh, something is still wrong, let me give it another try."**

5. Pour the contents of all four test tubes back into the beaker.

Fill the four test tubes again with the acidic solution and all of the test tubes will contain the colorless liquid.

DISCUSSION

If you are using this demonstration to introduce indicators, you might wish to leave the students with their curiosity aroused and inform them they will be able to explain this magic trick when they complete their lesson on indicators.

If you are using this demonstration to review indicators, you might wish to have students go ahead and explain the magic trick at this time.

It is suggested that you repeat the demonstration asking questions about each step.

What color was the liquid I poured from the beaker?

Answer -- The liquid from the beaker was clear and colorless.

Why did this clear colorless liquid turn bright pink in test tubes #1 and #3, but not in test tube #2?

Answer -- There must have been something in test tubes #1 and #3 that was not in test tube #2 that caused a chemical reaction.

Can you recall an indicator that would cause this chemical change?

Answer -- Yes, phenolphthalein turns bright pink in bases.

Why did tubes #1, #2, and #3 have pink solutions while #4 remained colorless after the second pouring?

Answer -- The solution in the beaker was pink due to the presence of phenolphthalein in a basic solution, test tube #4 must have had some acid in the bottom that changed the pH of the solution when it was poured into it. When the four test tubes were poured back into the beaker, the acid in #4 was enough to change the pH of the solution in the beaker so the last pouring was again a clear colorless solution.

WHAT IS AN ACID?

Laboratory Exercise
-- for the teacher --

PURPOSE

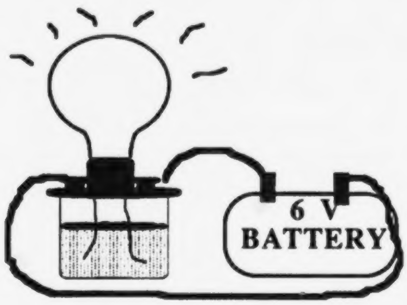
In this lab students will define acids in terms of the properties of acids.

MATERIALS

- Thin slices of lemon or lemon juice for taste test
- Dilute hydrochloric acid (dropper bottle labeled Acid A)
- Dilute sulfuric acid (dropper bottle labeled Acid B)
- Dilute acetic acid (dropper bottle labeled Acid C)
- Phenolphthalein (dropper bottle)
- Strips of red and blue litmus paper (place on glass plates)
- Limewater (calcium hydroxide solution)
- Calcium carbonate (powder)
- Magnesium strips (4 or 5 cm)
- Safety goggles
- Conductivity apparatus**
- Glassware:
    - small beakers for conductivity test
    - glass plates for litmus paper
    - test tubes for calcium carbonate reaction
    - glass bends and one-hole stoppers to fit the test tubes
- Spoon or spatula
- Bunsen burner and matches
- Wood splints

*You may wish to use 0.1 M solutions for all tests except the conductivity. You may wish to distribute the dilute acids for the conductivity test in small beakers labeled A, B, and C.

**The conductivity apparatus can be set up as illustrated below.



PRELABORATORY DISCUSSION

In chemistry students learn about many different compounds. One way to help students learn the most about compounds is to group compounds by properties. One way is to classify compounds as acids, bases, salts, and oxides. In this lesson we will identify the properties of three common acids. Why start with acids? Acids are important in industry as well as our daily lives. Acids are used in the steel industry, in fertilizer production, in explosives, and in the manufacturing of plastics, to mention a few. Acids are also found in our food and in many of our household products.

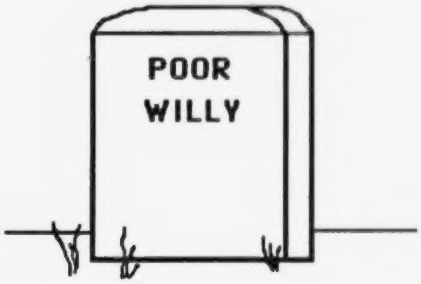
This lab activity can be done as a guided lab in which the class is divided into groups with each group testing a single acid. The observations can be collected and recorded using an overhead projector. If you do not wish to conduct the lab using a guided approach, you might need to demonstrate the lab techniques involved during your prelab discussion. Be certain to remind students that all acids should be handled with caution.

During this prelab discussion you might need to review the tests for gases.

GAS	TEST	RESULT OF TEST
Carbon dioxide	gas bubbled through limewater	limewater turns milky (cloudy)
Hydrogen	burning splint	a pop or bang
Oxygen	glowing splint	glowing splint bursts into flame

PROCEDURE 1: WHAT A TASTE!

Poor Willy was a chemist.
Now Willy is no more;
For what he thought was H_2O
Was H_2SO_4.



1. Obtain a thin slice of lemon or a sample of lemon juice. Taste is a property of acids: however, we do not want to make the same mistake Poor Willy made.

2. Taste your lemon. Lemons contain citric acid. This sour taste is characteristic of acids.

3. Record "sour" under the taste column for each acid listed on your data table.

PROCEDURE 2: COLORS WILL TELL

1. Place a strip of blue litmus paper and a strip of red litmus paper on a glass plate.

2. Touch the tip of the dropper from the dropper bottle labeled "Acid A" to each piece of litmus paper. Record your results.

3. Repeat step 2 with the other two acids.

4. Place 20 drops of Acid A into a small test tube.

5. Add one drop of phenolphthalein indicator to the acid in the small test tube. Record your observations and rinse your test tube.

6. Repeat steps 4 and 5 using the other two acids.

PROCEDURE 3: WHAT A GAS!

1. Fill a test tube 1/4 full with limewater.

2. Add about 5 ml of Acid A to another test tube

3. Tilt the test tube containing Acid A. Place a small amount of the calcium carbonate powder in the mouth of the test tube. Keep the test tube tilted so the acid and calcium carbonate do not mix.

4. Have your lab partner place the long end of the glass bend into the tube containing the limewater.

5. Working with your partner, insert the rubber stopper into the tube containing the acid.

6. Knock the calcium carbonate powder down into the acid so they react. Record your results.

7. Rinse all glassware.

8. Repeat steps 1-7 with the other two acids.

PROCEDURE 4: ANOTHER EXCITING GAS

1. Add 5 ml of Acid A to a test tube.

2. Place a small piece of magnesium ribbon in the tube.

3. Test the gas given off with a burning splint. Remember to wear safety goggles.

4. Record your results. Rinse your glassware.

5. Repeat steps 1-4 with the other two acids.

PROCEDURE 5: LET'S ADD LIGHT TO THE SUBJECT

1. Set up a conductivity apparatus.

2. Obtain a small beaker of Acid A. Test your sample of Acid A for conductivity.

3. Record your results. Rinse the probe of the conductivity apparatus.

4. Return "Acid A" as your teacher instructed. Repeat the conductivity test with the other two acids.

DATA AND OBSERVATION

The following data table is to be used with all procedures in this lab.

PROPERTIES OF ACIDS

	A	B	C
Taste	Sour	Sour	Sour
Litmus test	turns red	turns red	turns red
Phenolphthalein test	All will remain clear and colorless or will turn cloudy or white		
Reaction with $CaCO_3$	All will react to produce carbon dioxide gas		
Reaction with Mg	All will react with the Mg to produce hydrogen gas as a product		
Conducts Current	All will ionize and conduct current		
Common Ion	Since they all react the same, ionize and give off H, the common ion must be H^+		

CONCLUSION

From this lab the student should be able to make the following conclusions:

1. Acids are a group of compounds that have similar properties.
2. Acids can conduct a current; therefore acids must ionize.
3. Acids react with many metals to give off hydrogen gas; therefore, acids must have hydrogen as a common ion.

POSTLABORATORY DISCUSSION

Begin your postlab discussion by asking: "What makes an acid behave as it does?" "What common characteristic or structural feature can account for the properties of an acid?" Let's look over our data carefully for the answers to these questions.

If you did this lab as a guided activity, project the data for all to observe. If you did this lab as an independent group activity, you might have students compile their data on a class data table for all to share and examine. Guide the students through the data with the following questions:

How do the properties of all the acids compare?

Answer -- All have similar properties.

In the reaction of the acids with magnesium, where did the hydrogen gas come from?

Answer -- Since the magnesium is a pure element, and the acids are compounds, the hydrogen had to come from the acids.

Since all the acids are conductors, what can we say about how acids behave when dissolved in water?

Answer -- It is reasonable to say that acids produce ions when dissolved in water. The ions have charges and current is a flow of charges.

Based on all the observations we have made, what common ion do acids contain?

Answer -- The hydrogen ion (H^+) is the likely choice.

Examine the formulas for the acids we used in this lab. What atom do they all have in common that supports the hydrogen ion as the most likely choice of common ion?

Acid A	Hydrochloric acid	HCl
Acid B	Sulfuric acid	H_2SO_4
Acid C	Acetic acid	$HC_2H_3O_2$

Answer -- These acids all contain hydrogen atoms in combined form.

Based on the evidence we have, how might we define acids?

Answer -- Acids are a group of compounds with similar properties. An acid can be any substance that can release hydrogen ions in water solution.

WHAT IS AN ACID?
Laboratory Exercise
-- for the student --

PURPOSE

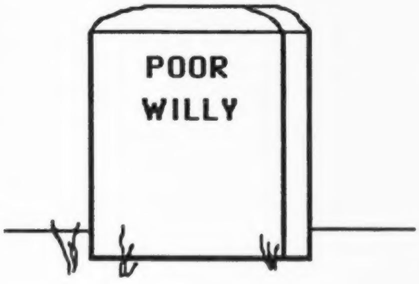
In this lab we will identify the properties of acids and define acids in terms of properties.

MATERIALS

- Lemon slice or lemon juice
- Phenolphthalein (dropper bottle)
- Strips of red and blue litmus paper
- Calcium carbonate (powder)
- Conductivity apparatus
- Spoon or spatula
- Bunsen burner
- Acid A
- Acid B
- Acid C
- Limewater
- Magnesium strips
- Wood splints
- Safety glasses
- Glassware:
  - small beaker
  - 2 test tubes
  - glass plate
  - glass bend with one-hole stopper
- From supply table:
  - Acid A for conductivity test
  - Acid B for conductivity test
  - Acid C for conductivity test

PROCEDURE 1: WHAT A TASTE!

Poor Willy was a chemist.
Now Willy is no more;
For what he thought was H_2O
Was H_2SO_4.



1. Obtain a thin slice of lemon or a sample of lemon juice. Taste is a property of acids: however, we do not want to make the same mistake Poor Willy made.

2. Taste your lemon. Lemons contain citric acid. This sour taste is characteristic of acids.

3. Record "sour" under the taste column for each acid listed on your data table.

PROCEDURE 2: COLORS WILL TELL

1. Place a strip of blue litmus paper and a strip of red litmus paper on a glass plate.

2. Touch the tip of the dropper from the dropper bottle labeled "Acid A" to each piece of litmus paper. Record your results.

3. Repeat step 2 with the other two acids.

4. Place 20 drops of Acid A into a small test tube.

5. Add one drop of phenolphthalein indicator to the acid in the small test tube. Record your observations and rinse your test tube.

6. Repeat steps 4 and 5 using the other two acids.

PROCEDURE 3: WHAT A GAS!

1. Fill a test tube 1/4 full with limewater.

2. Add about 5 ml of Acid A to another test tube.
3. Tilt the test tube containing Acid A. Place a small amount of the calcium carbonate powder in the mouth of the test tube. Keep the test tube tilted so the acid and calcium carbonate do not mix.

4. Have your lab partner place the long end of the glass bend into the tube containing the limewater.

5. Working with your partner, insert the rubber stopper into the tube containing the acid.

6. Knock the calcium carbonate powder down into the acid so they react. Record your results.

7. Rinse all glassware.

8. Repeat steps 1-7 with the other two acids.

PROCEDURE 4: ANOTHER EXCITING GAS

1. Add 5 ml of Acid A to a test tube.

2. Place a small piece of Magnesium ribbon in the tube.

3. Test the gas given off with a burning splint. Remember to wear safety goggles.

4. Record your results. Rinse your glassware.

5. Repeat steps 1-4 with the other two acids.

PROCEDURE 5: LET'S ADD LIGHT TO THE SUBJECT

1. Set up a conductivity apparatus.

2. Obtain a small beaker of Acid A. Test your sample of Acid A for conductivity.

3. Record your results. Rinse the probe of the conductivity apparatus.

4. Return "Acid A" as your teacher instructed. Repeat the conductivity test with the other two acids.

DATA AND OBSERVATIONS

The following data table is to be used with all procedures in this lab.

PROPERTIES OF ACIDS

	A	B	C
Taste			
Litmus test			
Phenolphthalein test			
Reaction with $CaCO_3$			
Reaction with Mg			
Conductivity			
Common Ion			

CONCLUSION

Look over your data table. Think about your observations then answer the following questions.

How do the properties of all the acids compare?

In the reaction of the acids with magnesium, where did the hydrogen gas come from?

Since all the acids are conductors, what can we say about how acids behave when dissolved in water?

Based on all the observations we have made, what common ion do acids contain?

Examine the formulas for the acids we used in this lab. What atom do they all have in common that supports the hydrogen ion as the most likely choice of common ion?

Acid A	Hydrochloric acid	HCl
Acid B	Sulfuric acid	H_2SO_4
Acid C	Acetic acid	$HC_2H_3O_2$

Based on the evidence we have, how might we define acids?

WHAT IS A BASE?

Laboratory Exercise

-- for the teacher --

PURPOSE

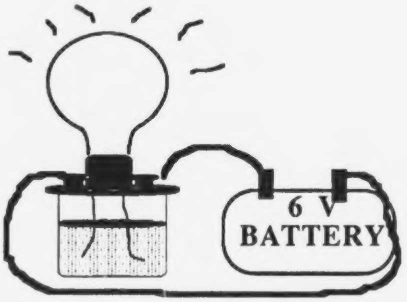
The purpose of this lab activity is to define bases in terms of the properties of bases.

MATERIALS

Strong baking soda solution (sodium hydrogen carbonate)
Dilute sodium hydroxide (dropper bottle labeled Base A)
Dilute potassium hydroxide (dropper bottle labeled Base B)
Dilute calcium hydroxide (dropper bottle labeled Base C)
Phenolphthalein (dropper bottle)
Strips of red and blue litmus paper (place on glass plate)
Safety goggles
Conductivity apparatus**
Glassware: small beakers for conductivity apparatus
small test tubes for phenolphthalein test
glass plates for the litmus paper test

*You may wish to use 0.1 M solutions for all tests except the conductivity. You may wish to distribute the dilute bases for the conductivity test in small beakers labeled Base A, Base B, and Base C.

**The conductivity apparatus can be set up by following the illustration given below.



PRELABORATORY DISCUSSION

Bases are just as important and just as loaded as acids. In this lab we will discover a definition for bases. Like acids, bases can be defined in terms of their properties.

Many bases are used in industry, in laboratories, and in household products. Sodium hydroxide, lye, is the main ingredient in drain cleaners, and in soap. Milk of magnesia is an antacid and is used as an antidote for acid poisoning. The main ingredient in milk of magnesia is magnesium hydroxide. Ammonium hydroxide is known as ammonia water. It is used as a general household cleaning agent.

Let's review acids before we move on to bases. Acids contain hydrogen ions, H^+. Acids turn blue litmus paper red, acids do not change the color of phenolphthalein, acids react with carbonates to produce carbon dioxide gas as a product, and acids ionize in water.

If your students need a memory clue for the litmus paper test, you might try the following:

Acid	**Red**	both end in **d**
Base	**Blue**	both begin with **b** and end in **e**

You may also need to review double displacement reactions, so students will be able to determine the products of the neutralization reaction.

PROCEDURE 1: HAVE TASTE, CAN BE DEADLY

One of the first rules of laboratory safety is never to taste the chemicals. In this case, we will make one exception. Your teacher has prepared a solution of sodium bicarbonate. Sodium bicarbonate is commonly called baking soda and is used in cakes and cookies. It forms a base in a water solution.

1. Wash your hands.
2. Place a small drop of sodium bicarbonate solution on your clean index finger.
3. Taste the drop of sodium bicarbonate. Would you describe the taste as sweet, sour, or bitter?
4. This bitter taste is a property of bases. Record "bitter" as the taste of all the bases on your data table.

Base	**Bitter**	**Blue**	all begin with **b**.

PROCEDURE 2: OH, WHAT A FEELING?

1. Place a drop of Base A between your fingers. Rub the drop between your fingers.
2. Rinse your fingers.
3. Record any unusual feeling in your data table.
4. Repeat the above steps with the other two bases.

PROCEDURE 3: ANOTHER COLORFUL TALE

1. Place a strip of blue litmus paper and a strip of red litmus paper on a glass plate.
2. Remove the dropper from the dropper bottle labeled "Base A". Touch the tip of the wet dropper to the litmus paper strips.
3. Record the color change.
4. Repeat steps 1-3 with the other two bases.
5. Place about 10 drops of "Base A" into a small test tube.
6. Add a drop of phenolphthalein indicator to the test tube containing the 10 drops of "Base A".
7. Record your observations.

8. Rinse your test tube and repeat steps 5-7 with the other two bases.

PROCEDURE 4: ADD A LITTLE LIGHT

1. Set up a conductivity apparatus.
2. Obtain a small beaker of "Base A" and test for conductivity.
3. Record your results. Rinse the probe of the conductivity apparatus.
4. Return "Base A" as your teacher instructed. Repeat the conductivity test with the other two bases.

PROCEDURE 5: CAN IT REACT?

You learned in the last procedure that bases ionize. You also learned in your study of acids that acids ionize. Let's look at a reaction between an acid and a base. It is called a neutralization reaction. It is a double displacement reaction. Study the following general equation.

Acid		Base		Salt		Water
AB	+	CD	--------------->	CB	+	AD

Compound AB is an acid that reacts with compound CD, a base, to produce a salt, CB and water AD. Remember, the positive ion is always written first. Ions A and C are positive while ions B and D are negative. In a double displacement reaction, the positive ions from two compounds replace each other to form two different compounds.

What ion do acids have in common?

Answer -- Acids have hydrogen ions (H^+) in common.

Which one of the two products also has this same ion?

Answer -- The water contains hydrogen ions.

The formula for water is H_2O, often written HOH. If the hydrogen came from the acid (letter A), where did the hydroxide come from?

Answer -- The hydroxide came from the base, letter D.

What are the products of a neutralization reaction between an acid and a base? (Write your answer here and on your data table).

Answer -- A salt (determined by the particular acid and base) and water.

Complete your data table.

DATA AND OBSERVATIONS

The following data table is to be used with all procedures in this lab.

PROPERTIES OF BASES

BASE	A	B	C
Taste	Bases have a bitter taste		
Feel	Bases feel slippery like soap		
Litmus test	Bases turn red litmus paper blue		
Phenolphthalein test	Bases turn phenolphthalein bright pink		
Conductivity	Bases are electrical conductors; therefore, they must ionize		
Reaction with acids	Bases react with acids to produce a salt and water		
Common ion	Bases produce hydroxide ions when dissolved in water		

CONCLUSION

Look over your data table. Think about your observations then answer the following questions.

How do the properties of bases A, B, and C compare?

Answer -- The properties are the same.

In the neutralization reaction between the acid and the base, where did the hydroxide ion in the water come from?

Answer -- The hydroxide ion came from the base.

Since bases are conductors, what can we say about how bases behave when dissolved in water?

Answer -- Bases ionize to form ions.

Examine the formulas for the bases used in this lab. What group of atoms do they all have in common that is supported by your data as being the common ion in bases?

Base A	Sodium hydroxide	Na(OH)
Base B	Potassium hydroxide	K(OH)
Base C	Calcium hydroxide	$Ca(OH)_2$

Answer -- OH or the hydroxide ion.

Based on the evidence you have, how might you define bases?

Answer -- A base is a substance that produces hydroxide ions in water. It can also neutralize an acid.

POSTLABORATORY DISCUSSION

Discuss the data and conclusion questions with the class. Summarize and compare the properties of acids and bases on the board as members of the class identify the properties for you. Your lists might be similar to the following.

Acids	Bases
1. electrical conductor	1. electrical conductor
2. react with Mg to form H_2 (gas)	2. neutralize acids
3. make blue litmus red	3. make red litmus blue
4. taste sour	4. taste bitter
5. frequently corrosive to skin	5. frequently corrosive to skin
	6. feel slippery

Point out to the class that their lists of properties give us an operational definition for acids and bases. They describe what an acid or base will do and how to recognize each. Your students also stated a conceptual definition for acids and bases when they began to state **why the acids and bases have their properties.**

You might consider following up this lab with an activity in which the students are given some common household products and asked to apply the information they gained from this lab and from the acid lab to determine which of the products are acids and which are bases.

WHAT IS A BASE?

Laboratory Exercise
-- for the student --

PURPOSE

The purpose of this lab activity is to define bases in terms of the properties of bases.

MATERIALS

Strong baking soda solution
Phenolphthalein (dropper bottle)
Strips of red and blue litmus paper
Safety goggles
Conductivity apparatus
Glassware:
  small beaker
  small test tube
  glass plate
From supply table:
  Base A for conductivity test
  Base B for conductivity test
  Base C for conductivity test

Base A
Base B
Base C

PROCEDURE 1: HAVE TASTE, CAN BE DEADLY

One of the first rules of laboratory safety is never to taste the chemicals. In this case, we will make an exception. Your teacher has prepared a solution of sodium bicarbonate. Sodium bicarbonate is commonly called baking soda and is used in cakes and cookies. It forms a base in a water solution.

1. Wash your hands.

2. Place a small drop of sodium bicarbonate on your clean index finger.

3. Taste the drop of sodium bicarbonate. Would you describe the taste as sweet, sour, or bitter?

4. This bitter taste is a property of bases. Record "bitter" as the taste of all the bases on your data table. See DATA AND OBSERVATIONS.

Base **Bitter** **Blue** all begin with **b.**

PROCEDURE 2: OH, WHAT A FEELING

1. Place a drop of Base A between your fingers. Rub the drop between your fingers.

2. Rinse your fingers.

3. Record any unusual feeling in your data table.

4. Repeat the above steps with the other two bases.

PROCEDURE 3: ANOTHER COLORFUL TALE

1. Place a strip of blue litmus paper and a strip of red litmus paper on a glass plate.

2. Remove the dropper from the dropper bottle labeled "Base A". Touch the tip of the wet dropper to the litmus paper strips.

3. Record the color change.

4. Repeat steps 1-3 with the other two bases.
5. Place about 10 drops of "Base A" into a small test tube.
6. Add a drop of phenolphthalein indicator to the test tube containing the 10 drops of "Base A".
7. Record your observations.
8. Rinse your test tube and repeat steps 5-7 with the other two bases.

PROCEDURE 4: ADD A LITTLE LIGHT

1. Set up a conductivity apparatus.
2. Obtain a small beaker of "Base A" and test for conductivity.
3. Record your results. Rinse the probe of the conductivity apparatus.
4. Return "Base A" as your teacher instructed. Repeat the conductivity test with the other two bases.

PROCEDURE 5: CAN IT REACT?

You learned in the last procedure that bases ionize. You also learned in your study of acids that acids ionize. Let's look at a reaction between an acid and a base. It is called a **neutralization** reaction. It is a double displacement reaction. Study the general equation. Then answer the guide questions.

Acid		Base		Salt		Water
AB	+	CD	-------->	CB	+	AD

Compound AB is an acid that reacts with compound CD, a base, to produce a salt, CB and water, AD. Remember, the positive ion is always written first. Ions A and C are positive while ions B and D are negative. In a double displacement reaction, the positive ions from two compounds replace each other to form two different compounds.

What ion do acids have in common?

Which one of the two products also has this same ion?

The formula for water is H_2O, often written HOH. If the hydrogen came from the acid (letter A), where did the hydroxide come from?

What are the products of a neutralization reaction between an acid and a base? (Write your answer here and on your data table).

Complete your data table.

DATA AND OBSERVATIONS

The following data table is to be used with all procedures in this lab.

PROPERTIES OF BASES

BASE	A	B	C
Taste			
Feel			
Litmus test			
Phenolphthalein test			
Conductivity			
Reaction with acids			
Common ion			

CONCLUSION

Look over your data table. Think about your observations then answer the following questions.

How do the properties of bases A, B, and C compare?

In the neutralization reaction between the acid and the base, where did the hydroxide ion in the water come from?

Since bases are conductors, what can we say about how bases behave when dissolved in water?

Examine the formulas for the bases used in this lab. What group of atoms do they all have in common that is supported by your data as being the common ion in bases?

Base A	Sodium hydroxide	$Na(OH)$
Base B	Potassium hydroxide	$K(OH)$
Base C	Calcium hydroxide	$Ca(OH)_2$

Based on the evidence you have, how might you define bases?

COLORS WILL TELL

Laboratory Exercise

-- for the teacher --

PURPOSE

The purpose of this lab activity is to investigate the effect of acids and bases upon indicator solutions.

MATERIALS*

Test tubes (5)
Glass-marking pencil
50-ml graduated cylinder
Test tube rack
Distilled water
Medicine dropper
Litmus solution
Phenolphthalein
Stirring rod
Dilute hydrochloric acid
Dilute sodium hydroxide
Congo red solution
Grape juice
Tea solution
Red cabbage juice
Unknown solution

*Prepare a set of indicator solutions and dilute acid and base solutions for every two lab groups. Dropper bottles are ideal for dispensing indicators. Eight bottles will be needed for each complete set. Cigar boxes make good containers for the sets of bottles.

Preparation of solutions (acids, bases, and indicators)

Dilute (2 molar) hydrochloric acid--Mix 83 milliliters of concentrated (11.7 molar) HCl with 417 milliliters of distilled water to make one-half liter of solution.

Dilute (2 molar) sodium hydroxide solution--Dissolve 40 grams of sodium hydroxide pellets in one-half liter of water.

Litmus solution--Dissolve 5 grams of powered litmus in 500 milliliters of distilled water. Adjust the color of the litmus solution to an intermediate purple between the basic dark blue and the acidic red by adding a few drops of dilute HCl or NaOH.

Phenolphthalein--Dissolve 5 grams of powered phenolphthalein in 250 milliliters of denatured alcohol. Add 250 milliliters of distilled water.

Congo Red--Dissolve 5 grams of powered Congo red dye in 500 milliliters of distilled water.

Grape Juice--Purchase bottled grape juice from the grocery store (example Welch's). Dilute with an equal volume of distilled water.

Tea--Boil several tea bags in 500 milliliters of distilled water for several minutes to produce a strong tea solution.

Red Cabbage Juice--Chop up several red cabbage leaves and boil in 500 milliliters of distilled water until the leaves are colorless, then filter or decant solution. This is a must as an indicator. Your students will enjoy the very vivid colors. This is also the best indicator to differentiate between the different concentrations of both acids and bases.

Beet Juice (optional)--Chop fresh or frozen beets and place in distilled water; allow beets to soak in water for 10 to 15 minutes. You may also decant the solution from a large can of beets.

If the test tubes are filled with solutions as directed in the lab procedure and tested with beet juice, the following results should be obtained:

Test tubes #1, #2, and #3 will be pink, #4 light brown and #5 yellow.

Unknown--Put some of the original dilute HCl and NaOH solutions in several numbered dropper bottles. Record the substance that each bottle contains. Other different solutions may be used, such as white vinegar, ammonia water, or fruit juices.

Adapted from (Teacher's Edition with Annotations of) Physical Science: A Problem Solving Approach by Joseph L. Carter, et al., © Copyright, 1974, 1977, by Silver Burdett & Ginn Inc. Used with permission.

PRELABORATORY DISCUSSION

Substances, such as litmus, which change color as the concentrations of acid or base solutions change are called **indicators.** Litmus, phenophthalein and congo red are commercially prepared indicator solutions. There are also several food extracts that change color as acidity of the solution changes. Tea, red cabbage juice, and grape juice have this property of changing color as the acidity of the solution changes.

Remind students of lab safety rules, especially when using acids and bases. You might wish to demonstrate the use of solid baking soda, $NaHCO_3$, as an acid neutralizer. As long as bubbles of carbon dioxide are given off, there is still acid present (property of acids to react with carbonates to release carbon dioxide). When the bubbling stops, the remaining solution will be neutral or slightly basic as tested by an appropriate indicator.

This lab will take two class periods if each lab group studies all of the indicators. If time is limited you might wish to assign the indicators to different lab groups, then display and discuss the results before the unknowns are tested.

PROCEDURE 1: COMMERCIAL INDICATORS

1. Number five large test tubes from 1 to 5 with a glass marking pencil.

2. Place the five test tubes in numerical order in a test tube rack. Add 10 milliliters of distilled water to each of the five test tubes.

3. Add three drops of litmus solution to each of the test tubes. Stir each with a clean stirring rod.

4. Add the acids and bases to the test tubes as listed below, stir after each addition.

Test tube #1	add three drops of dilute hydrochloric acid
Test tube #2	add one drop of dilute hydrochloric acid
Test tube #3	do not add anything, this is the control tube since water is usually neutral--neither acidic nor basic.
Test tube #4	add one drop of dilute sodium hydroxide
Test tube #5	add three drops of dilute sodium hydroxide

5. Compare the five test tubes with each other and record the color of the liquid in each tube on your data table. You will use the same data table (see DATA AND OBSERVATIONS) for all procedures in this lab.

6. Discard the solutions in each test tube and rinse each tube.

7. Repeat steps 1-6 using three drops of phenolphthalein instead of litmus in each test tube. Add the acids and bases to each tube exactly as instructed in step 4.

8. Record the color of the solution in each test tube on your data table.

9. Discard the solutions, rinse the test tubes, and repeat steps 1-6 using three drops of Congo red indicator.

PROCEDURE 2: COMMON HOUSEHOLD INDICATORS

1. Place the five clean test tubes, labeled #1, #2, #3, #4, and #5, in your test tube rack. Add 10 milliliters of diluted grape juice to each test tube.

2. Add the acids and bases as directed below, and stir after each addition.

Test tube #1	add three drops of dilute hydrochloric acid.
Test tube #2	add one drop of dilute hydrochloric acid.
Test tube #3	this is the control, do not add anything to the grape juice.
Test tube #4	add one drop of sodium hydroxide.
Test tube #5	add three drops of sodium hydroxide.

3. Observe and record the colors of the solutions on your data table.

4. Discard the solutions, rinse the test tubes and repeat steps 1-3 using 10 milliliters of strong tea in place of the grape juice.
5. Observe and record the color of the solutions on your data table.

6. Discard the solutions, rinse the test tubes and repeat steps 1-3 using 10 milliliters of undiluted red cabbage juice.

7. Observe and record the color of the solutions on your data table.

PROCEDURE 3: TESTING AN UNKNOWN SOLUTION

1. Pour 10 milliliters of distilled water into a clean test tube.

2. Add three drops of your unknown solution to the test tube, then add three drops of litmus solution.

3. Record your observations. Repeat steps 1 and 2 two more times. Use phenolphthalein in place of the litmus solution for the second trial, and Congo red solution for the third trial. Clean the test tube thoroughly before each trial.

4. Identify your unknown solution as an acid or a base and state the reasons for your choice.

DATA AND OBSERVATIONS

How did the number of drops of acid or base added to each test tube affect the solution in the test tube?

Answer -- The number of drops of acid or base added increased the acidity or basicity of the solution. Tube #1 was most acidic with three drops of hydrochloric, then #2 with one drop of hydrochloric and #5 was the most basic with three drops of sodium hydroxide. In other words, the acidity decreased from tube #1 to #5 while the basicity decreased from tube #5 to #1. Tube #3 is neutral.

How did the number of drops of acid or base added to each test tube affect the indicator added to the solutions?

Answer -- In most cases, the concentration of the acid or base in the solution produced a more pronounced color effect on the indicator.

DATA TABLE

	ACIDIC SOLUTIONS (HCl)		NEUTRAL	BASIC SOLUTIONS (NaOH)	
INDICATOR	3 Drops	1 Drop		1 Drop	3 Drops
Litmus Solution	light red	light red	purplish-blue	blue	blue
Phenolphthalein	colorless	colorless	colorless	light pink	light pink
Congo red Solution	deep blue	deep blue	red	red	red
Grape juice	pale purple	pale purple	pale purple	deep purple	blue-black
Tea	light yellow	light yellow	yellow	brown	brown
Red cabbage juice	red	pink	blue	green	yellow-green

TESTING AN UNKNOWN	Litmus	Phenolphthalein	Congo Red
Unknown #______			
Unknown # is a/an acid/base.			

To which kind of solution is the grape juice most sensitive?

Answer -- The grape juice did not change color in the acid but changed to a blue-black color in the basic solution; therefore, grape juice is most sensitive to basic solutions.

Look at your data table. Which indicator is most sensitive to changes in concentration of both acid and base solutions?

Answer -- The red cabbage juice is the most sensitive as indicated by its color changes in both concentrations of the acid and both concentrations of the base. (The colors changed from red to pink to blue to green to yellow-green as the concentration of hydrogen ions decreased.)

CONCLUSION

Explain how indicators can be used to identify solutions as being an acid or a base. Write your answer in complete sentences and name specific indicators and the color changes that identify acids and bases.

POSTLABORATORY DISCUSSION

Large colored charts of the color ranges for each indicator should be prepared in advance for use in discussing the results of this experiment. An alternate visual aid that could be prepared is a series of slides or transparencies showing test tubes tinted the appropriate colors for each indicator.

Questions discussed might include the following:

What are some limitations to the use of indicators?

Answer -- Solutions in which they are to be used successfully must be colorless. Otherwise, the color of the solution might mask the color changes of the indicator.

The human eye cannot always distinguish very slight color changes.

Most of the indicators seem to change color over a very narrow range of the pH scale. To test for pH over a wide range, many indicators must be used.

What are some uses for indicators other than in the science laboratory?

Answer -- Testing water in swimming pools or aquaria, and in soil test kits.

You might wish to **demonstrate** that an indicator remains in the solution through various color changes. Add several milliliters of cabbage juice indicator to a liter of distilled water. Add by the drop concentrated hydrochloric acid while stirring. First a pink color then a red color will appear. Then add concentrated sodium hydroxide solution dropwise with stirring, and watch the color change back to pink, neutral blue, and finally to green and yellow-green in a basic solution.

Changing indicator colors are due to the transfer of protons to and from the molecules of the indicator, so the process may be reversed indefinitely.

COLORS WILL TELL

Laboratory Exercise

-- for the student --

PURPOSE

The purpose of this lab activity is to investigate the effect of acids and bases upon indicator solutions.

MATERIALS

Test tubes (5)
Glass-marking pencil
50-ml graduated cylinder
Test tube rack
Distilled water
Medicine dropper
Litmus solution
Phenolphthalein
Stirring rod
Dilute hydrochloric acid
Dilute sodium hydroxide
Congo red solution
Grape juice
Tea solution
Red cabbage juice
Unknown solution

PROCEDURE 1: COMMERCIAL INDICATORS

1. Number five large test tubes from 1 to 5 with a glass marking pencil.

2. Place the five test tubes in numerical order in a test tube rack. Add 10 milliliters of distilled water to each of the five test tubes.

3. Add three drops of litmus solution to each of the test tubes. Stir each with a clean stirring rod.

4. Add the acids and bases to the test tubes as listed below, stir after each addition.

Test tube #1	add three drops of dilute hydrochloric acid
Test tube #2	add one drop of dilute hydrochloric acid
Test tube #3	do not add anything, this is the control tube since water is usually neutral--neither acidic nor basic.
Test tube #4	add one drop of dilute sodium hydroxide
Test tube #5	add three drops of dilute sodium hydroxide

5. Compare the five test tubes with each other and record the color of the liquid in each tube on your data table. You will use the same data table (See DATA AND OBSERVATIONS) for all procedures in this lab.

6. Discard the solutions in each test tube and rinse each tube.

7. Repeat steps 1-6 using three drops of phenolphthalein instead of litmus in each test tube. Add the acids and bases to each tube exactly as instructed in step 4.

8. Record the color of the solution in each test tube on your data table.

9. Discard the solutions, rinse the test tubes, and repeat steps 1-6 using three drops of Congo red indicator.

PROCEDURE 2: COMMON HOUSEHOLD INDICATORS

1. Place the five clean test tubes, labeled #1, #2, #3, #4, and #5, in your test tube rack. Add 10 milliliters of diluted grape juice to each test tube.

Adapted from (Teacher's Edition with Annotations of) Physical Science: A Problem Solving Approach by Joseph L. Carter, et al., © Copyright, 1974, 1977, by Silver Burdett & Ginn Inc. Used with permission.

2. Add the acids and bases as directed below, and stir after each addition.

Test tube #1	add three drops of dilute hydrochloric acid.
Test tube #2	add one drop of dilute hydrochloric acid.
Test tube #3	this is the control, do not add anything to the grape juice.
Test tube #4	add one drop of sodium hydroxide.
Test tube #5	add three drops of sodium hydroxide.

3. Observe and record the colors of the solutions on your data table.

4. Discard the solutions, rinse the test tubes and repeat steps 1-3 using 10 milliliters of strong tea in place of the grape juice.

5. Observe and record the color of the solutions on your data table.

6. Discard the solutions, rinse the test tubes and repeat steps 1-3 using 10 milliliters of undiluted red cabbage juice.

7. Observe and record the color of the solutions on your data table.

PROCEDURE 3: TESTING AN UNKNOWN SOLUTION

1. Pour 10 milliliters of distilled water into a clean test tube.

2. Add three drops of your unknown solution to the test tube, then add three drops of litmus solution.

3. Record your observations. Repeat steps 1 and 2 two more times. Use phenolphthalein in place of the litmus solution for the second trial, and Congo red solution for the third trial. Clean the test tube thoroughly before each trial.

4. Identify your unknown solution as an acid or a base and state the reasons for your choice.

DATA AND OBSERVATIONS

	ACIDIC SOLUTIONS (HCl)		NEUTRAL	BASIC SOLUTIONS (NaOH)	
INDICATOR	3 Drops	1 Drop		1 Drop	3 Drops
Litmus Solution					
Phenol-phthalein					
Congo red Solution					
Grape juice					
Tea					
Red cabbage juice					

TESTING AN UNKNOWN	Litmus	Phenolphthalein	Congo Red
Unknown #_______			

Unknown # is a/an acid/base.

How did the number of drops of acid or base added to each test tube affect the solution in the test tube?

How did the number of drops of acid or base added to each test tube affect the indicator added to the solutions?

To which kind of solution is the grape juice most sensitive?

Look at your data table. Which indicator is most sensitive to changes in concentration of both acid and base solutions?

CONCLUSION

Explain how indicators can be used to identify solutions as being an acid or a base. Write your answer in complete sentences and name specific indicators and the color changes that identify acids and bases.

Nuclear Chemistry 7

Background Information

While the nuclei of all the atoms of a particular element have the same number of protons, they do not always have the same number of neutrons. Atoms of the same element with different numbers of neutrons are called **isotopes** of the element. It is similar to the situation in a family. The Jones family has several members and each has a different name, height, and weight. Yet they are all Joneses. An element can be considered like a family. For instance, with **uranium,** all family members have 92 protons. One isotope has 143 neutrons and is called uranium-235. Another isotope has 146 neutrons and is called uranium-238. The 235 and 238 are the atomic masses (weights) of each isotope.

Atoms can be stable or unstable. The number of stable isotopes of a given element ranges from zero (technetium, promethium, and all elements with more protons than lead) to nine (xenon) and ten (tin). The number of unstable isotopes is nearly unlimited. The stability of an atom depends on the ratio of the number of neutrons to protons in the nucleus. This ratio is closely related to the forces needed to hold these particles together. Stable atoms contain just the right amount of energy to hold themselves together. An unstable atom contains too much energy in its nucleus and gets rid of the excess energy by undergoing fundamental changes in its structure. These changes in the structure and hence in the chemical identity of the nucleus result in a more stable atom. The dynamic result of these fundamental changes is the subject of this unit.

During the Middle Ages, alchemists searched for chemical reactions that would change lead into gold. The search, of course, failed. Chemical reactions can only combine elements, separate them, or regroup them. However, nuclear reactions, that is, reactions in which the nucleus undergoes basic structural changes, can result in one element changing into another. There are three processes by which this can occur: Radioactive decay, fission, and fusion.

RADIOACTIVE DECAY

One method by which an atom can emit energy and become more stable is to spontaneously emit its excess energy in the form of **radiation.** Radiation is the propagation of radiant energy in the form of waves or particles. When an atom emits radiation, it is said to undergo **radioactive decay** or **disintegration.**

Radiation is a very broad term and includes radio waves, infrared heat waves, visible light, ultraviolet light, X-rays, and gamma rays. It also includes beams of particles such as electrons, neutrons, and protons. Although you can see light radiation and feel the heat of infrared radiation, you cannot directly sense ultraviolet radiation, although it does cause effects such as sunburn. In the context of this chapter, radiation will generally mean ionizing radiation. This radiation has enough energy to strip electrons away from the shells of atoms of material that it passes through, creating charged particles. Ionizing radiation cannot be sensed directly.

Atoms of a few natural elements are radioactive but most radioactive isotopes are artificially produced. The elements uranium, thorium, and radium, for instance, are naturally radioactive. When nuclei of uranium, thorium, and radium decay, they break up or disintegrate in a series of steps called a decay chain. The first step turns them into another element called the daughter of the original element. The daughter is also radioactive and breaks up to produce another radioactive nucleus or daughter and so on. In the last step, the daughter nucleus in each case is an isotope of lead which is stable and not radioactive.

NATURAL RADIOACTIVE DECAY CHAINS

There are three major radioactive decay chains that occur in nature. Uranium-238 and all the isotopes and elements into which it decays form a chain known as the **uranium series.** Uranium-235 is the beginning of another radioactive chain known as the **actinium series.** Thorium-232 is the beginning of a third chain known as the **thorium series.** Every nucleus in the thorium series has a mass number that is a multiple of 4, so the series is called the 4n series. For example, the mass number of Th-232 is a multiple of 4 (4 x 58 = 232) and the first daughter after decay is Ra-228 (4 x 57 = 238). For the uranium series, the mass number is 2 higher than a multiple of 4 (4n+2) and for the actinium series, the mass number is 3 higher than a multiple of 4 (4n+3). There is no 4n+1 series in nature, because every element in that chain has decayed away, but it can be artificially produced starting with the isotope plutonium-241 (4 x 60 +1). This chain is called the **neptunium series** and ends with the stable nucleus bismuth-209.

HISTORY

The history of the discovery of the nature of radioactivity is filled with names of Nobel Prize winners, some of whom are listed below:

Roentgen - discovered X-rays in 1895 and was awarded the Nobel Prize in 1903.

Becquerel and Marie and Pierre Curie - discovered materials that were naturally radioactive such as uranium, polonium, and radium. They were awarded the Nobel Prize in 1903.

Fredric and Irene Joliot-Curie - first produced artificially-induced radioactive materials. They were awarded the Nobel Prize in 1935.

Cockcroft, Walton, Lawrence, and Fermi all received Nobel Prizes for discovering additional ways to create artificial radioactivity, such as with the cyclotron.

TYPES OF RADIATION

The three most common forms of ionizing radiation are known as **alpha, beta,** and **gamma.** Alpha radiation is a particle similar to a helium nucleus that is positively charged (no electrons, 2 protons plus 2 neutrons). While it is one of the heaviest radioactive particles, it can travel only 2-3 inches in air, has very little penetrating power, and can be stopped by a piece of paper. Beta radiation is an electron, negatively charged, that while very light (1/2000 the mass of a proton) can travel 4-5 inches in air and can be stopped by thin pieces of wood or several sheets of aluminum foil. Gamma radiation consists of electromagnetic high energy photons that can travel several hundred yards in air and require 1-2 feet of concrete to stop. As an aside, X-rays are low energy photons. Gamma rays are electromagnetic in nature, act as waves, and travel at the speed of light. See Figures 1 and 2.

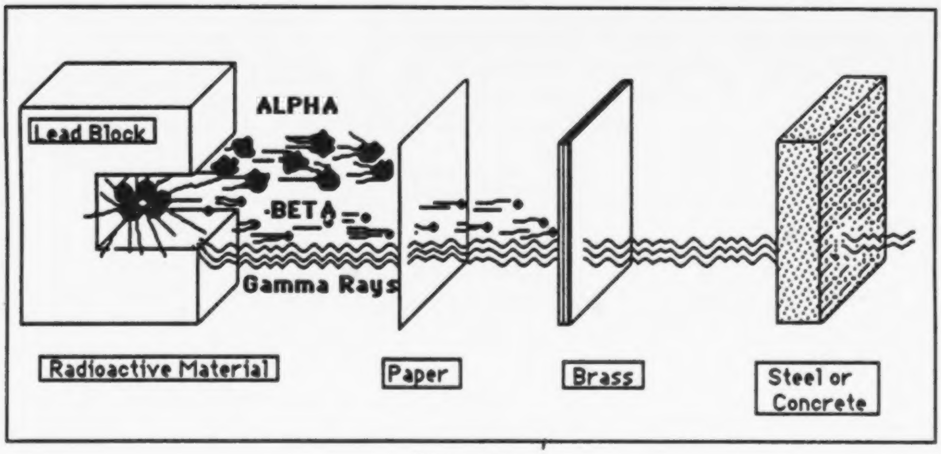

Lead Block
ALPHA
BETA
Gamma Rays
Radioactive Material
Paper
Brass
Steel or
Concrete

Figure 1.
The Penetration Power of Radiation

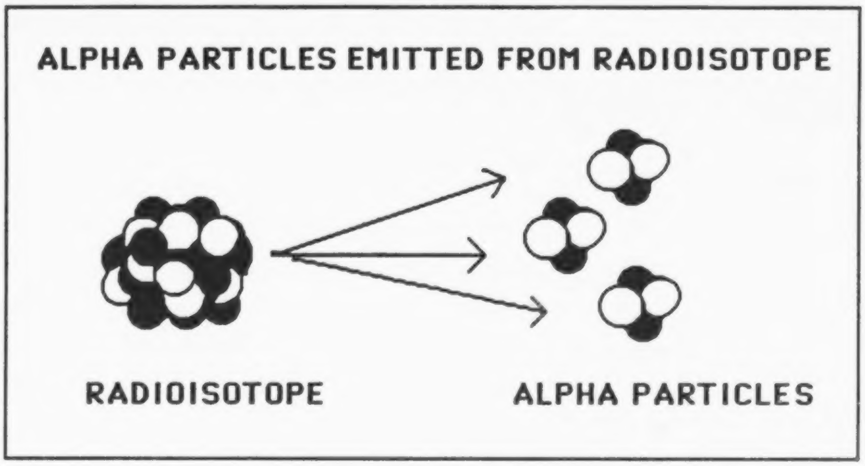

ALPHA PARTICLES EMITTED FROM RADIOISOTOPE
RADIOISOTOPE
ALPHA PARTICLES

Figure 2.

RADIOACTIVE HALF-LIFE

Radioactive nuclei do not disintegrate all at once. In a sample of a radioactive isotope of an element, only a fraction of the nuclei will break up in any one second. The rate of radioactive decay is a function only of the structure of the unstable nucleus. It does not depend on any of the factors that affect chemical reactions such as temperature or pressure.

Radioactive decay is a random process similar to that of flipping a coin -- there are only two outcomes, heads or tails, and what happens each time the coin is tossed does not depend on what happened the previous toss. Similarly, at a point in time, an atom either emits radiation or it does not. It is impossible to predict which particular atom of a substance will disintegrate next or at what precise moment a disintegration will occur. However, using probability theory, one can calculate the probability that a given number of nuclei will disintegrate in a given time interval. The time needed for a specific fraction of a very large number of atoms of a particular radioactive isotope to disintegrate is a constant number, known as the decay constant. The time it takes for 50% of the atoms to decay is called the radioactive half-life. It is a measure of the average life expectancy of a radioactive isotope.

For example, if one starts at midnight with 10 grams of the isotope N-13, with a half-life of 10 minutes, then at 12:10 a.m., there will be 10 ÷ 2 = 5 grams left with 5 grams having decayed away; at 12:20 a.m., there will be 5 ÷ 2 = 2.5 grams left with 2.5 grams having decayed away, etc.

Some 15 hours later there will be only one atom left that has a 50-50 chance of decaying within the next ten minutes. After 10 half-lives have elapsed, the amount of material left to disintegrate has dwindled to 1/1024 (giving a denominator of 2 raised to the 10th power) of the original amount, which normally is very small. As time passes, since there are less and less atoms remaining, the amount of radiation emitted continually decreases. Some typical half-lives are shown in Table 1.

The process is similar to that occurring with a leaky tire. When the tire pressure is high, there are many air molecules compressed near the hole in the tire and they escape quickly. As the pressure drops due to leakage, fewer air molecules are near the hole and each air molecule must travel further and further to reach it. Eventually only a few air molecules will be left to drift out of the hole.

RADIATION MEASUREMENT UNITS

The term used to express the number of disintegrations per second for a radioactive isotope is known as a **curie**, with one curie defined as follows: 1 Curie = 3.7×10^{10} = 37 billion disintegrations/second. A curie measures the activity or intensity present, but does not give any indication as to the type or energy of the radiation.

There is a relationship between the intensity or activity and half-life of a radioactive element. Radioactive material with a high level of activity has to be decaying at a fast and furious rate, and hence must have a short half-life. Radioactive material decaying at a low level of activity has a long half-life or it would not last so long. In fact, a stable element has an infinite half-life.

Table 1

HALF-LIVES OF A FEW RADIOACTIVE ISOTOPES

hydrogen-3 (tritium)	12.26 years
carbon-14	5730 years
oxygen-13	0.0087 seconds
oxygen-14	71.0 seconds
oxygen-19	124 seconds
oxygen-20	14 seconds
chlorine-36	310,000 years
potassium-40	1,280,000,000 years
cobalt-60	5.26 years
polonium-212	0.000000304 seconds
radon-216	0.0000045 seconds
uranium-235	710,000,000 years
neptunium-237	2,200,000 years
uranium-238	4,510,000,000 years
plutonium-244	80,000,000 years
plutonium-246	10.9 days

There is no neptunium-237 found in nature, while uranium-238 is found. In order for N-237 to have decayed away the age of the earth must be many billions of years old.

Radiation can destroy, damage or disturb the normal function of living cells. For radiation external to the body , the effects depend on the type and energy of the radiation, its intensity, the period of exposure and the extent to which the body is irradiated. For radioactive isotopes inside the body, the effects depend on the interaction of the body with the isotope, including such things as the affinity of the isotope for a particular organ (Strontium-90 deposits in the bone), the time the material remains in the body, the type and energy of the radiation emitted, and the half-life. Thus, a meaningful measurement of radiation needs to take into account its biological effects, which depend on all of the factors previously mentioned. This measurement is called the radiation dose. The term for the unit used to express radiation dose is called the **rem** (roentgen equivalent man). A rem measures radiation's biological effect in the same way that degrees gauge temperature and inches distance. Because the radiation levels generally encountered by human beings are usually low, the term normally used is **millirem (mrem)**, which is 1/1000 of a rem. The use of the term rem enables one to make unqualified similar comparisons. It corresponds to some absorbed dose causing a similar biological effect no matter what the characteristics of the radiation involved. For instance, one rem of alpha radiation has the same biological effect as one rem of gamma radiation. However, in contrast with the curie, one curie of alpha radiation does not have the same biological effect as one curie of gamma radiation.

RADIATION PROTECTION

There are three ways to provide protection against external sources of radiation - distance, time and shielding. See Figure 3. As far as time is concerned, clearly, the shorter the time one is exposed to the radiation, the safer one is.

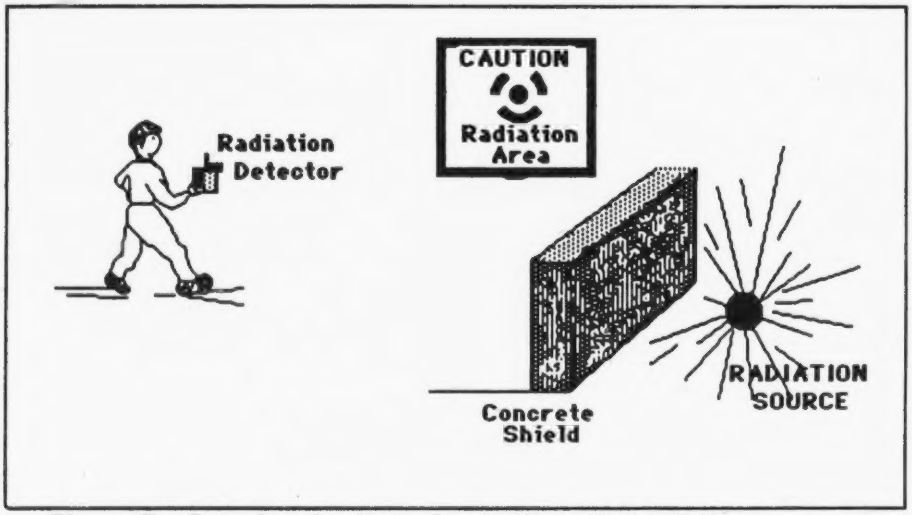


Figure 3. Examples of methods of protection against radiation.

Since radiation is emitted spherically (in all directions) from a point, its intensity decreases with distance out from the point by the necessity of the same amount having to be spread over a larger and larger area. See Figure 4. This area is the area of the outside surface of a sphere - $4\pi r^2$, where r is the radius of the sphere. Since the area increases with the square of the distance from the point, the radiation intensity therefore **decreases** with the square of the distance. Thus, a radioactive source measured as 40 curies at a point one foot from the source will measure 10 curies at two feet (the distance has doubled, so the intensity decreases by 2 squared = 4, 40/4=10), 2.50 curies at four feet, etc. Increasing the distance between a person and a radioactive source, therefore, can result in the radioactivity decreasing very rapidly in intensity. One can visualize this effect with a balloon, painted with circular polka dots all over it. The polka dots on a balloon grow to four times their original size when the balloon is blown up to twice its original radius.

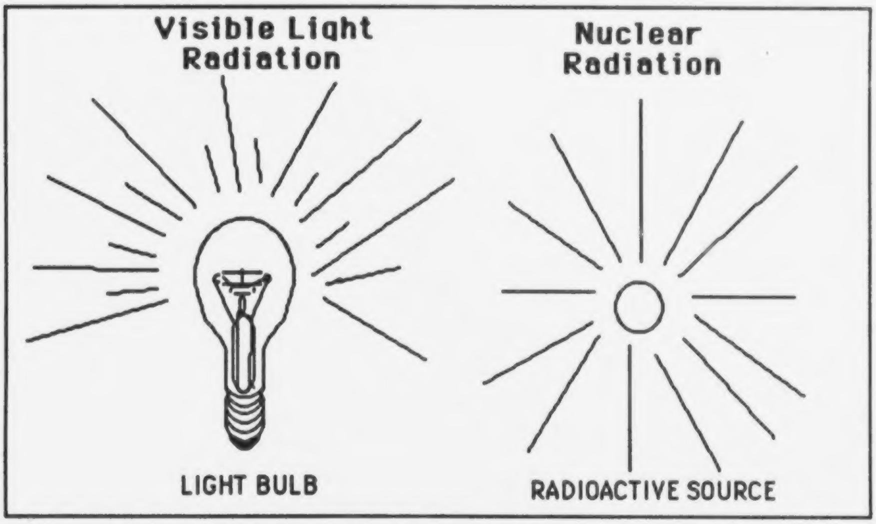


FIGURE 4: Radioactive emissions

Shielding, or the placing of material between you and the radiation source, is also effective since radiation will interact with matter. Charged particles, like alpha and beta rays, penetrate matter very poorly because they expend so much energy during interaction with other charged particles near the surface of the shielding material. Gamma rays, having no electrical charge and acting like waves, are unaffected by the electrical force, and thus can penetrate farther than alpha or beta, but still lose energy in interactions with atoms of the material.

For protection against ingesting radiation orally or breathing it in, the source of radiation can either be isolated from human beings or rendered harmless. Radioactive material can be stored in a safe place by itself and kept away from people or be diluted with large volumes of air or water so that its concentration becomes very small. Also, if the half-life is short, the radioactive material will soon decay away and no longer be potentially dangerous.

One of the unique and advantageous characteristics of radiation is that a radioactive element loses its toxicity with time as it decays away. On the other hand, non-radioactive materials remain **toxic forever.** It has been reported by the director of the Mario Negri Research Institute in Milan that after the disasterous accidental chemical release in Seveso, Italy in July, 1976, there is still no sign that the toxicity of the dioxin deposited in that town is diminishing.

Another unique and favorable aspect of radiation is that it can be instantly detected in the environment with appropriate instrumentation. Thus, accidental spills are easily cleaned up thoroughly. Locating all the chemicals from a chemical spill is a far more difficult task since the chemicals do not emit something that can be measured by a detector.

There are international standards set for maximum permissible radiation doses to people to assure their safety. These standards are regularly reviewed and updated. They have been established by the International Commission for Radiation Protection, founded in 1928, and adopted by the U.S. Nuclear Regulatory Commission (NRC) for use in this country. Some examples of the limits are:

Exposed Part of Body	Radiation Worker	Member of the Public
Whole body	5 rem/year	0.5 rem/year
Skin & bone	30 rem/year	------------
Hands & feet	75 rem/year	------------

The standard warning symbol for radioactivity is shown in Figure 5.

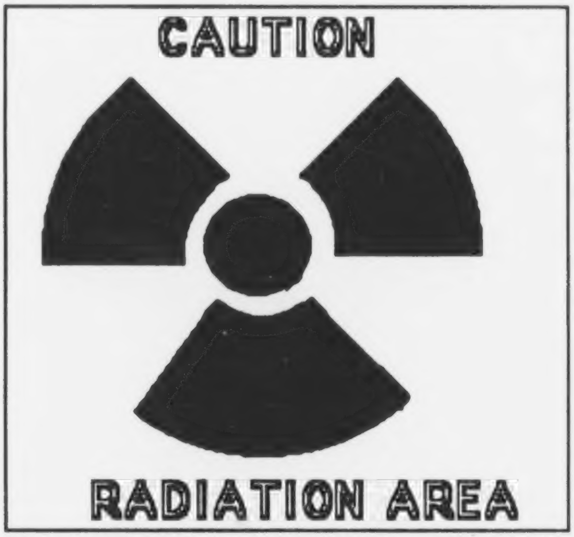


Figure 5. Standard warning symbol for radioactivity.

RADIATION IS ALL AROUND US

Radiation is everywhere. The **earth** is a radioactive planet. Every plant and animal that has ever lived on this earth has been bathed in radiation for every second of its life. Scientists believe man and animals have been exposed to 50-100 mrem per year continuously for millions of years. This is known as natural background radiation. There is radioactivity in the ground, the air, the buildings we live in, the food we eat, the water we drink and the products we use. Cosmic rays from outer space bombard the earth incessantly. **You are radioactive!** Radioactive isotopes of potassium, carbon, and hydrogen are continuously present in your body.

Uranium is a part of the earth's crust and is therefore present in all hard building materials (stone, bricks, cement). It decays into the radioactive gas radon and radon daughters. These are short-lived isotopes and thus are very intense in radioactivity. Radon is an inert gas and therefore does not chemically combine with anything. It diffuses upward in the soil and is released into the atmosphere and homes. It stays inside if the home is tightly sealed. Some estimates for doses to occupants of very tight homes range upwards of several hundred mrem/year. Granite is radioactive. An area near the west basement door outside the Library of Congress gives a dose of 344 mrem per year. This is 70 times greater than that permitted by the NRC at the boundary of a nuclear power plant. Soil and rocks in Colorado result in a dose of 105 mrem/year, in Connecticut 60 mrem/year, in Kerala, India 3000 mrem/year, and at a beach in Guarapari, Brazil 5 mrem per **hour.** Radiation is present in almost every step of the food chain including drinking water. In some places on earth, doses of over 1000 mrem per year are received from the food people eat. Mining minerals, burning fuels, building structures and other social activities also redistribute natural radioactive elements found in the earth's crust and expose people to radiation they normally would not be expected to receive.

Cosmic rays from outer space come mainly from the center of the Milky Way. They produce radioactive isotopes in the atmosphere that eventually enter living matter. Radioactive carbon-14, one of those isotopes produced in the atmosphere by cosmic rays, is present in the carbon dioxide assimilated by plants and eaten by man. It is used for "carbon dating" the age of objects such as fossils and rocks. One receives more radiation at higher elevations since there is less atmosphere to shield the cosmic rays. Colorado has double the background radiation of Florida but one-half the cancer rate. This does not mean that natural background radiation reduces cancer but only that background radiation is not among the dominant causes of cancer. For every 100 foot increase in elevation, one receives an increase of 1 mrem/year in radiation dose. Airline pilots receive a dose of 400 mrem/year because of their profession.

Radiation is present in consumer products, such as color TV's, smoke detectors and luminous dial watches. Smoking two packs of cigarettes per day results in a dose to the small parts of the lung of 10,000 mrem/year due to the natural radioactive polonium in the smoke.

Some other examples of everyday radiation exposures are shown in Table 2.

Table 2

TYPICAL RADIATION DOSES

Background radiation received by every human on the average:	
Cosmic rays	30 - 45 mrem/yr
Nuclear weapons test fallout	4 - 7 mrem/yr
Medical	70 mrem/yr
Soil, rocks	35 - 40 mrem/yr
Air, food, water	25 - 30 mrem/yr
	165-190 millirem/year
Other sources:	
Fertilizer	2 mrem/yr
Chest X-ray	20 mrem/yr
Working in the US Capitol Building	4 mrem/yr
Working in the Grand Central Station, NYC	120 mrem/yr
Flying in an airplane	1 mrem/yr/ 1500 mi flown
Natural gas stove in your home	2 mrem/yr
Gasoline lantern mantle	5 to 20 mrem/yr
Sleeping with another human	0.1 mrem/yr
Living in Colorado instead of Houston	an extra 80 mrem/yr
Living in a brick house	50-100 mrem/yr
concrete house	70-100 mrem/yr
wooden house	30-50 mrem/yr
Smoke detectors	2 mrem/yr
Luminous clocks	9 mrem/yr
Three Mile Island Acccident	80 mrem
Living near a nuclear plant	1 mrem/yr
Therapeutic X-ray to a single organ	5,000,000 mrem
Lethal dose to 50% of humans receiving this dose over entire body	400,000-500,000 mrem
Minimum amount to detect any biological effect	25,000 mrem/yr
Maximum allowable annual average exposure for radiation worker	5,000 mrem/yr

BENEFICIAL USES OF RADIATION

The benefits associated with the use of machines and materials that produce radiation are many. In the medical area, radiation is employed in medical diagnosis and treatment, and in sterilization of medical supplies. It is used to assess the condition and functioning of various body organs such as the heart, lungs, brain, liver, and kidney and to cure diseases such as cancer. In fact, today doctors use radioactive materials to help diagnose nearly one-half of the patients in major hospitals. Radioactive sterilization of medical supplies is advantageous in that the undesirable residues that sometimes accompany chemical sterilization are not left behind. In addition, using radiation is the only way to sterilize certain heat sensitive medical items, such as plastic heart valves.

Radioactive isotopes have two advantages in medical applications. First, they can be used in extremely small amounts -- one billionth of a gram can be measured. Second, they can be directed to various specific parts of the body. For instance, radioactive iodine behaves in the body chemically the same way as normal iodine. And iodine tends to concentrate in the thyroid. Other radioactive atoms can be routed to the bone marrow, red blood cells, liver, and kidneys. Once there, the amount can be determined by a radiation detection instrument and the conclusions can be made by a physician as to the condition and functioning of that specific bodily area.

There are also industrial uses of radiation. As a tracer, radiation can be used to follow material through a process since radioactive and nonradioactive isotopes of the same element have identical chemical properties. Radiation can also pass through some material but not all, depending on the thickness and density of the material and the energy of the radiation. Thus, it is used for finding voids in metal castings, testing welds, taking pictures of concealed objects (X-rays at the doctor's office or at airport checkpoints), and oil well logging. Radiation also has energy and that energy can be converted into heat and then into electricity as in nuclear power plants. These provide electricity for large cities, for small unmanned weather stations, such as in the Artic, or for space satellites.

BIOLOGICAL EFFECTS OF RADIATION

Americans drive automobiles to work, on errands, and for pleasure. Many relax by swimming and boating and traveling by airplane. These activities continue despite a general awareness that some 50,000 people are killed in traffic accidents each year. Nearly 6,000 people drown each year, and more than 1,500 deaths are caused by aircraft crashes. Immediate and visible in their impact, these dangers are concrete and familiar. Society accepts them almost routinely.

Radiation arouses anxiety in people more for its potential risk than for its actual hazard. This is because the general populace considers it to be a new, unknown force that cannot be detected by the senses and that causes unique injuries which may not appear for many years. In fact, radiation produces no biological damage that does not also occur from other natural physical and chemical causes. Radiation has been studied extensively for more than 90 years and is the most scientifically understood, easily detected, precisely measured, effectively controlled and strictly regulated of all environmental agents.

There are two types of radiation injuries, somatic and genetic. Somatic injuries affect our body tissues potentially causing biological changes. Genetic injuries affect our reproductive cells potentially causing hereditary changes.

Various events can occur when radiation passes through a cell. It can cause tissue injury by breaking apart chemical bonds causing the cell to die, to be unable to divide or to divide uncontrollably. It can also damage the cell by ionizing atoms in a molecule essential to the normal functioning of the cell. The ions may recombine before any damage is done or the radiation may pass through the cell and not ionize anything. The cell may repair some or all of the damage or be killed. The latter is not lethal to an organism since the dead cell cannot pass on false instructions. In fact, using radiation to destroy a cell is one means for cancer treatment, where cancer cells are the ones destroyed.

There is convincing medical evidence that certain levels of radiation increase the normal chance of someone eventually developing cancer. However, this evidence comes only from those few groups of people subjected to massive radiation doses, from hundreds of thousands to millions of millirem. These groups include early pioneers in medical radiology, their patients treated with X-rays, and victims of Hiroshima and Nagasaki. Many more people have been studied extensively over several decades to determine if a link between radiation level and increased chances of cancer exists at lower levels of exposure. Below about 100 rem, all experience with human adults has generally been that no significant link exists. Apparently below this threshold level, the damage caused by radiation is less than the damage caused by other factors.

Hereditary illness related to radiation has been observed in laboratory experiments only with animals. None has ever been discovered in humans, although it would be prudent to assume it could.

Both the somatic and genetic types of injuries associated with radiation cannot be distinguished from those occurring naturally and caused by other factors. For instance, leukemia induced by radiation cannot be distinguished from leukemia caused by viruses or chemicals. Further, these injuries may not develop for several decades after the exposure assumed to produce them. At low doses therefore, hundreds of millions of people would have to be carefully investigated for many years to reveal any statistically significant increase in fatal cancers or inherited disorders. Potential hazards of low exposures have only been calculated mathematically and not observed. While a handful of scientists have claimed much greater harmful effects for lower levels of radiation, their evidence has been thoroughly discredited by the general scientific community after detailed peer reviews.

Removing radiation from society would not significantly reduce cancer mortality or genetic diseases. In fact, by using other methods to perform the same services, the death rate might increase. It is estimated that some 400,000 people in the United States die from cancer each year and that perhaps 4,500 of these are due to all sources of radiation. Some 390,000 children are born each year affected by a hereditary disability and perhaps 420 of these are caused by all sources of radiation. It is estimated that 25% of all cancers are caused by chemical pollutants, 35% by dietary factors, 10-20% by spontaneous events in the body, and 20-30% by other environmental factors.

There have been studies that indicate that radiation delivered at low rates can lengthen life. This has been observed in some animals, with the thought being that infection is reduced. The flour beetle life expectancy has been shown to increase by 30% if approximately 3,000 rem is delivered at the rate of 10 rem per minute.

In evaluation of all of these factors, one should remember, as stated earlier, that man is continuously being bombarded with natural radiation. If the human body did not have the ability to overcome the effects of this radiation, the human species would have died out long ago.

FISSION

Fission is the process in which a neutron strikes the nucleus of an atom of a heavy element like uranium and is absorbed. This absorbed neutron makes the heavy atom nucleus so unstable that it splits apart (fissions) into two lighter weight atoms (fission products). The fission products are new elements different than the original uranium. They are also radioactive. Several additional neutrons and a great deal of heat are released during the process. See Figure 6. The additional neutrons can go on to split other heavy atoms making more neutrons and so on. This is known as **a chain reaction.** By controlling the speed of the chain reaction, one can control the amount of the heat produced. The amount of energy produced in the fission can be determined from Einstein's formula

$$E = mc^2$$

where m represents the change in mass and c the velocity of light. This formula is applicable because the total mass of all the products after the reaction turn out to be a little less than those of the starting materials. This means some of the mass was converted to energy.

The first **self-sustaining** (continuing by itself once it has begun) nuclear chain reaction was attained by a team of scientists lead by Enrico Fermi on December 2, 1942, at the University of Chicago. This was part of a large-scale effort by the government to develop atomic military weapons during World War II, the Manhattan Project.

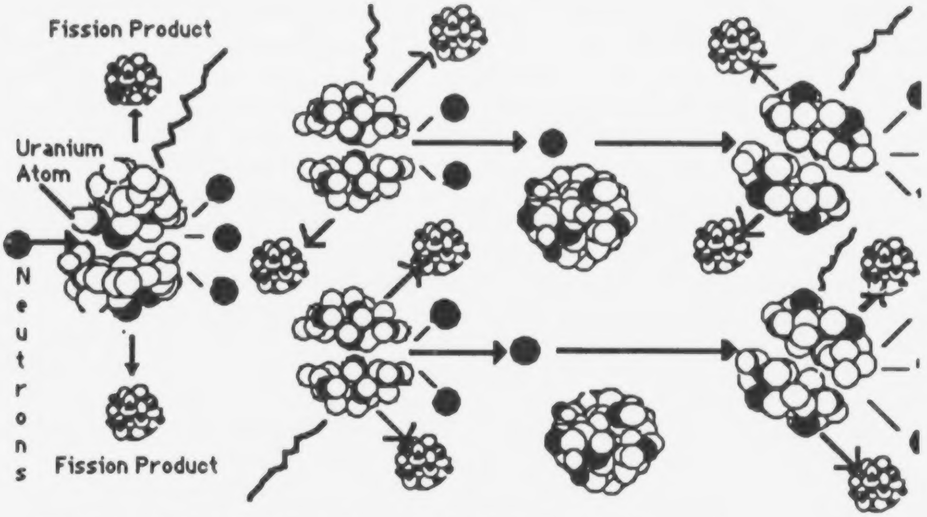


Figure 6. Nuclear fission chain reaction of a radioactive element.

After the war, scientists also began to develop nuclear energy for peaceful uses. One use was the development of nuclear power **reactors** to produce electricity. Today more and more of our electricity is being produced by nuclear power plants.

While man has built and operated nuclear reactors only recently, scientists have discovered the remains of a natural nuclear reactor in a uranium mine in Oklo, Gabon, Africa that existed almost two billion years ago. Water from an underground spring and the uranium combined underground under pressure and formed a nuclear reactor which generated heat for thousands of years.

Uranium is the key element from which nuclear power derives its energy. When prepared in its purest metallic form, uranium is a silvery white solid, much heavier than lead. It is composed of two different atomic isotopes--a heavy variety called uranium-238, or U-238, and a lighter and rare species known as U-235. It is the latter that is used in electrical power production. However, it constitutes only 0.7% of natural uranium, the rest (99.3%) being U-238. No amount of natural uranium, with only 0.7% U-235, could ever be used in a reactor of American design to economically produce power. This is because fission of U-238 does not release enough neutrons to continue a chain reaction, whereas fission of U-235 does. If, however, the natural uranium is processed (enriched) to produce a higher percentage of U-235, then the possibility of producing power becomes a reality.

Neither natural uranium nor the high enrichment weapons-grade uranium (greater that 93% U-235) are used in reactors that constitute the principal designs of U.S. nuclear power plants. Instead, uranium, enriched or fortified so that it contains approximately 2% to 3% of U-235, forms the basis of nuclear fuel for U.S. power reactors. This low percentage of U-235 in the reactor's fuel makes it physically impossible to have an accident in which a nuclear explosion can take place. Additionally, the physical configuration of the uranium fuel, or core as it is commonly called, is such as to further negate the possibility of an explosion.

The majority of Americans, however, do believe that a nuclear power plant can blow up like an atomic bomb. The fear and hysteria that surrounded the Three Mile Island and Chernobyl accidents, fueled by the media, helped reinforce that belief. Scientists and engineers normally do not make absolute statements, because usually in nature most anything is possible. However, this is one instance when one can say absolutely that a nuclear power plant cannot explode like an atomic bomb--never, under any conditions.

Uranium-235 is an energy powerhouse. **One cubic foot of U-235** contains the energy equivalent of 1.7 million tons of coal or 7.2 million barrels of oil. Fission of a nucleus releases far more energy than a chemical process such as burning.

In a conventional coal-fired electric generating plant, powdered coal is blown into a combustion space known as a boiler. As the powdered coal is burned, the heat generated is used to convert water into steam. This conversion takes place in tiers of pipes on the wall of the boiler. Steam at high temperature and under high pressure then travels out of the boiler and is piped to a huge turbine where the energy of the steam is transferred to the turbine blades causing the turbine shaft to rotate much like a windmill. Attached to the turbine shaft is an electrical generator. The electrical generator consists of a rotor and a large magnet attached to the rotor, with the magnet being located inside many coils of wire. As the turbine shaft rotates, the rotor in the generator rotates producing electricity in the coils of wire. A nuclear power plant is different in only one aspect. The uranium-fueled core of a nuclear reactor substitutes for the blazing boiler of the conventional fossil fueled steam-electric plant. And uranium produces heat by undergoing fission, not by being burned, as coal is. See Figure 7.

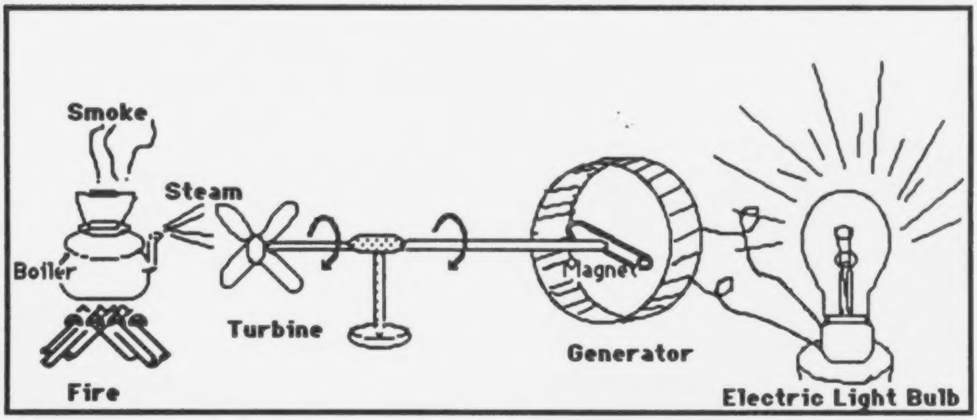


Figure 7. Making electricity by spinning a magnet inside a coil of wire.

Unlike the cavernous volume of a coal boiler, the nuclear core is a compact source of heat. Instead of water-filled pipes that line the walls of a coal boiler, a modern U.S. reactor consists primarily of a heavy steel reactor pressure vessel filled with water that circulates endlessly through channels around clusters of slender fuel rods. These rods are actually long tubes of non-corroding metal that are 12-14 feet long and are filled with uranium oxide fuel pellets. These fuel pellets are shaped like small ceramic cylinders, and are less than 1/2 inch in diameter and 1/2 inch in height. There are around 300 fuel pellets per rod. Depending on the type of reactor, these rods form a cluster in the shape of a square sized 8 x 8 (64 rods) to 17 x 17 (289 rods) in what is known as a fuel assembly. Upwards of 200 assemblies represent a full load of fuel. Thus, there are over 50,000 fuel rods and 16,000,000 fuel pellets in a reactor. It is inside of these fuel pellets that the fission process takes place and the heat is released. See Figure 8.

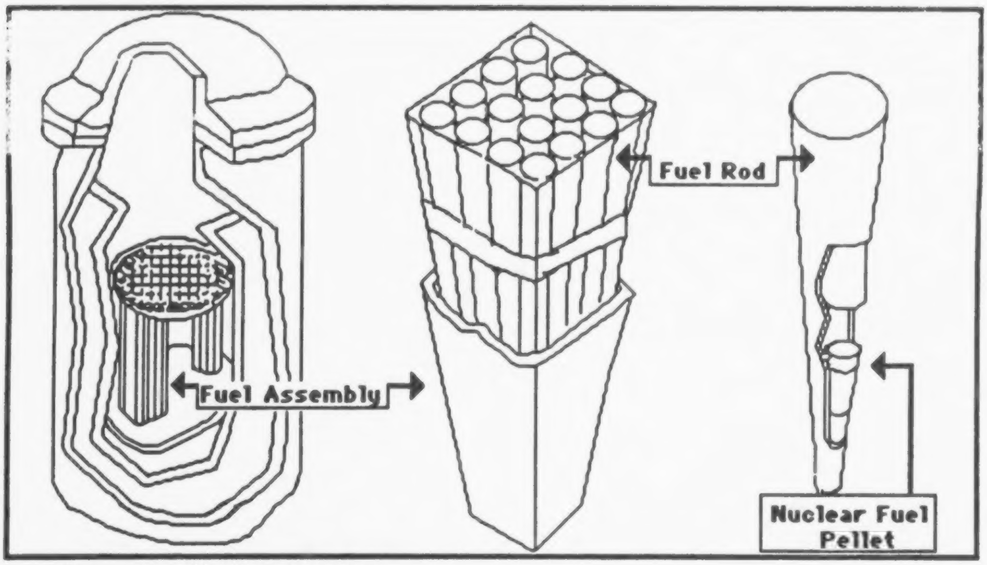


Figure 8. A Nuclear Reactor

Any engine or heat source has a starter, an accelerator and a shut-off mechanism. A nuclear reactor is no exception, but its starter, accelerator, and shut-down apparatus are one and the same --a system of control rods that move in and out of the reactor core. Control rods are composed of a material such as cadmium or boron. This material absorbs neutrons and thus prevents the neutrons from fissioning the uranium atoms.

When one assembles a "sufficient" number of fuel assemblies in the reactor core so that a chain reaction can occur, the control rods are fully inserted into the core. Withdrawing the control rods ("start up") removes the cadmium or boron from the core. This allows the successive splitting of uranium atoms to build up to a self-sustaining chain reaction. Further withdrawal of the control rods speeds up the tempo of the chain reaction since the rods absorb fewer of the neutrons.

There are presently over 100 nuclear power plants operating in the United States. They produce over 15% of the nation's electricity.

FUSION

Fusion is the process in which light nuclei like hydrogen combine to form heavier nuclei. Fusion is the exact opposite of fission. The energy of the sun comes from fusion. Here hydrogen atoms combine to form helium. Energy is released during the process, since the mass of the helium atom is less than the sum of the masses of the hydrogen atoms, and Einstein's equation applies. Thus, as with fission, some mass has been converted to energy.

Since light atoms are very stable, a considerable amount of energy is needed to make the nuclei come together. The fusion reaction occurs in nature only at temperatures found in the stars, of many millions of degrees. Only at these temperatures can enough energy be present to cause fusion to occur. No material on the earth will remain solid at these temperatures, so fusion reactions produced by man are held together by magnetic fields rather than steel vessels, such as with fission.

Controlled fusion as an energy source is only in the very early stages of development. However, since the elements that undergo the reaction are commonplace (found in ordinary water), the potential for unlimited energy is great. One gallon of seawater contains enough hydrogen isotopes for fusion to equal the energy released by burning 300 gallons of gasoline. See Figure 9.

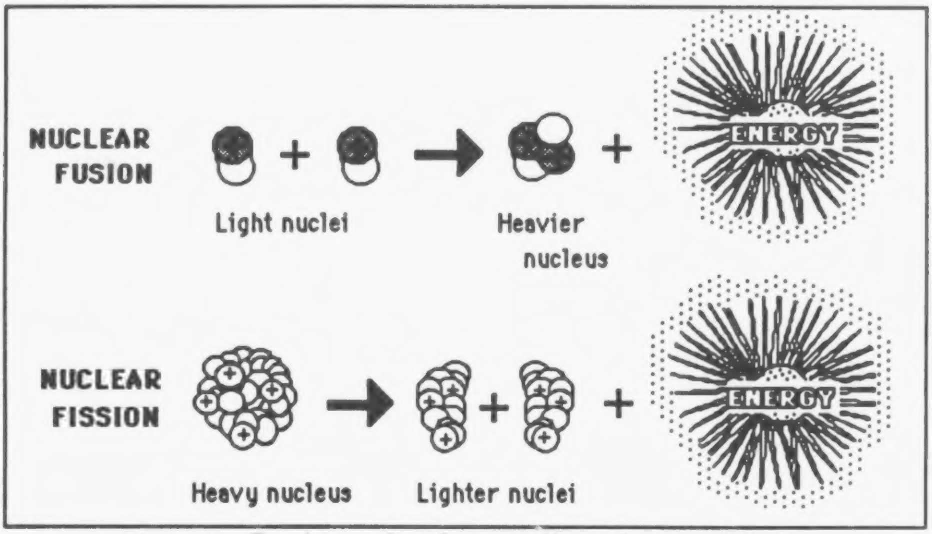
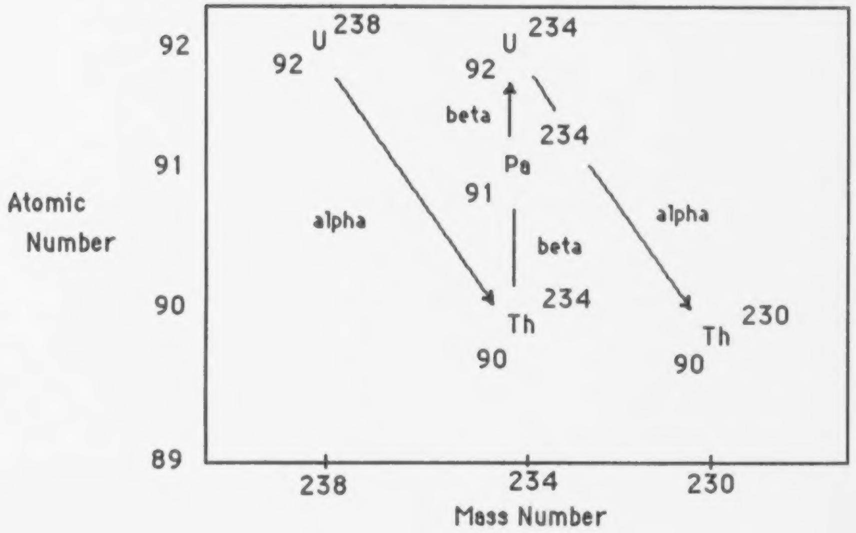

NUCLEAR FUSION
Light nuclei
Heavier nucleus
ENERGY
NUCLEAR FISSION
Heavy nucleus
Lighter nuclei
ENERGY

Figure 9. Two types of nuclear reactions, fusion and fission.

DECAY CHAIN OF URANIUM-238

Paper and Pencil Exercise

--for the teacher--



PURPOSE

As radioactive elements emit alpha and beta particles, the original elements change into a series of other elements. In these exercises, you will learn how to construct the natural decay chain of uranium-238 and radium-226. This will give you a better understanding of what takes place in the nuclei of radioactive elements.

PROCEDURE

1. Provide students with the necessary background information to complete the paper and pencil exercises that illustrate the radioactive decay of uranium and radium. Begin with the the figure above which demonstrates what changes take place when an alpha particle is given off and when a beta particle is given off. Point out that an alpha decay produces a new atom with an atomic number two less than the original one, and a mass number four less than before. This is because an alpha particle carries away two protons and two neutrons. In beta decay, the new atom has an atomic number one greater than the original atom. This is because a neutron transforms into a proton, which increases the atomic number by one with no change in the mass of the atom. Also, an electron (beta particle) is given off. Some students may have trouble understanding that in beta decay the atomic number increases by one and the atomic mass remains the same even though a particle is emitted from the nucleus.

Place this figure on the chalkboard and ask students to write each step in an equation as shown on Paper and Pencil Exercise - 1. Your version has the completed equations, but the students' do not. Go through a few examples of alpha decay and beta decay. Table 1 (only in teacher's version) will also help you describe what takes place in the decay of a radioactive element.

2. When you are sure that students can explain and write a nuclear equation illustrating alpha decay and beta decay, ask them to complete Paper and Pencil Exercise - 1. When they complete the exercise go over the answers.

3. Now ask the students to do Paper and Pencil Exercise - 2. Follow this exercise by going over the answers.

Be sure to call on many students to respond and demonstrate their knowledge of these basic concepts. Ask questions, wait and give students time to think, then call on many students to respond. Call students to the chalkboard to write the equations.

Table 1

DECAY CHAIN OF URANIUM-238

Step	Element	Event
1	Uranium	$^{238}_{92}U$ emits an alpha particle, forming $^{234}_{90}Th$
2	Thorium	$^{234}_{90}Th$ emits a beta particle, forming $^{234}_{91}Pa$
3	Protactinium	$^{234}_{91}Pa$ emits a beta particle, forming $^{234}_{92}U$
4	Uranium	$^{234}_{92}U$ emits an alpha particle, forming $^{230}_{90}Th$
5	Thorium	$^{230}_{90}Th$ emits an alpha particle, forming $^{226}_{88}Ra$
6	Radium	$^{226}_{88}Ra$ emits an alpha particle, forming $^{222}_{86}Rn$
7	Radon	$^{222}_{86}Rn$ emits an alpha particle, forming $^{218}_{84}Po$
8	Polonium	$^{218}_{84}Po$ emits an alpha particle, forming $^{214}_{82}Pb$
9	Lead	$^{214}_{82}Pb$ emits a beta particle, forming $^{214}_{83}Bi$
10	Bismuth	$^{214}_{83}Bi$ emits a beta particle, forming $^{214}_{84}Po$
11	Polonium	$^{214}_{84}Po$ emits an alpha particle, forming $^{210}_{82}Pb$
12	Lead	$^{210}_{82}Pb$ emits a beta particle, forming $^{210}_{83}Bi$
13	Bismuth	$^{210}_{83}Bi$ emits a beta particle, forming $^{210}_{84}Po$
14	Polonium	$^{210}_{84}Po$ emits an alpha particle, forming $^{206}_{82}Pb$
	Note: $^{206}_{82}Pb$ is stable	

Paper and Pencil Exercise - 1
RADIOACTIVE DISINTEGRATION OF URANIUM-238

Complete the disintegration of U^{238} in the fourteen steps below.

1. $^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$
2. $^{234}_{90}Th \longrightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e$
3. $^{234}_{91}Pa \longrightarrow {}^{234}_{92}U + {}^{0}_{-1}e$
4. $^{234}_{92}U \longrightarrow {}^{230}_{90}Th + {}^{4}_{2}He$
5. $^{230}_{90}Th \longrightarrow {}^{226}_{88}Ra + {}^{4}_{2}He$
6. $^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$
7. $^{222}_{86}Rn \longrightarrow {}^{218}_{84}Po + {}^{4}_{2}He$
8. $^{218}_{84}Po \longrightarrow {}^{214}_{82}Pb + {}^{4}_{2}He$
9. $^{214}_{82}Pb \longrightarrow {}^{214}_{83}Bi + {}^{0}_{-1}e$
10. $^{214}_{83}Bi \longrightarrow {}^{214}_{84}Po + {}^{0}_{-1}e$
11. $^{214}_{84}Po \longrightarrow {}^{210}_{82}Pb + {}^{4}_{2}He$
12. $^{210}_{82}Pb \longrightarrow {}^{210}_{83}Bi + {}^{0}_{-1}e$
13. $^{210}_{83}Bi \longrightarrow {}^{210}_{84}Po + {}^{0}_{-1}e$
14. $^{210}_{84}Po \longrightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$
15. Are any isotopes of lead radioactive? (Answer -- Yes, $^{214}_{82}Pb$, $^{210}_{82}Pb$)

Paper and Pencil Exercise - 2
Radioactive Disintegration of Radium-226

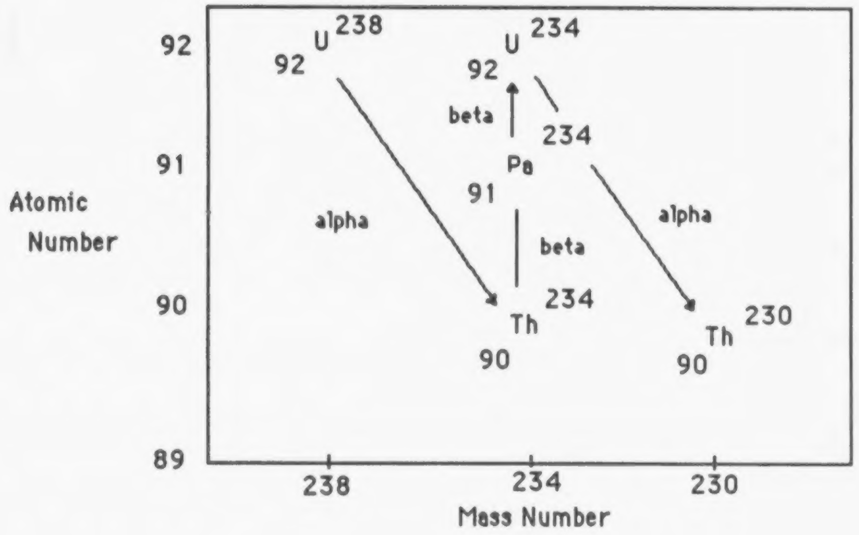
Complete the following decay chain of Radium-226:

1. ${}^{226}_{88}\text{Ra} \dashrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$
2. ${}^{222}_{86}\text{Rn} \dashrightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He}$
3. ${}^{218}_{84}\text{Po} \dashrightarrow {}^{214}_{82}\text{Pb} + {}^{4}_{2}\text{He}$
4. ${}^{214}_{82}\text{Pb} \dashrightarrow {}^{214}_{83}\text{Bi} + {}^{0}_{-1}e$
5. ${}^{214}_{83}\text{Bi} \dashrightarrow {}^{210}_{81}\text{Tl} + {}^{4}_{2}\text{He}$
6. ${}^{210}_{81}\text{Tl} \dashrightarrow {}^{210}_{82}\text{Pb} + {}^{0}_{-1}e$
7. ${}^{210}_{82}\text{Pb} \dashrightarrow {}^{210}_{83}\text{Bi} + {}^{0}_{-1}e$
8. ${}^{210}_{83}\text{Bi} \dashrightarrow {}^{210}_{84}\text{Po} + {}^{0}_{-1}e$
9. ${}^{210}_{84}\text{Po} \dashrightarrow {}^{206}_{82}\text{Pb} + {}^{4}_{2}\text{He}$

DECAY CHAIN OF URANIUM-238

Paper and Pencil Exercise

-- for the student --



PURPOSE

As radioactive elements emit alpha and beta particles, the original elements change into a series of other elements. In these exercises, you will learn how to construct the natural decay chain of uranium-238 and radium-226. This will give you a better understanding of what takes place in the nucleus of radioactive elements.

PROCEDURE

1. Participate in a teacher-led discussion on alpha and beta decay. Be sure you understand the nuclear reactions illustrated in the figure above and can write these reactions using formulas.

2. Complete Paper and Pencil Exercise - 1, which is attached. Go over the equations and check your answers with the teacher before going on to the next exercise.

3. Complete Paper and Pencil Exercise -2, which is attached. Go over the equations and check your answers with the teacher.

REVIEW

1. What takes place in the nucleus of a radioactive element when an alpha particle is given off?

____

____

2. What takes place in the nucleus of a radioactive element when a beta particle is given off?

____

____

Paper and Pencil Exercise - 1
RADIOACTIVE DISINTEGRATION OF URANIUM-238

Complete the disintegration of U^{238} in the fourteen steps below.

1. $^{238}_{92}\text{U}$ ----------> $^{234}_{90}\text{Th}$ + $^{4}_{2}\text{He}$
2. $^{234}_{90}\text{Th}$ ----------> ^{234}Pa + $^{0}_{-1}e$
3. $^{234}_{91}\text{Pa}$ ----------> U + $^{0}_{-1}e$
4. U ----------> Th + $^{4}_{2}\text{He}$
5. Th ----------> $^{226}_{88}\text{Ra}$ + ______
6. Ra ----------> ^{222}Rn + ______
7. $^{222}_{86}\text{Rn}$ ----------> Po + $^{4}_{2}\text{He}$
8. ______ ----------> $_{82}\text{Pb}$ + $^{4}_{2}\text{He}$
9. $^{214}_{82}\text{Pb}$ ----------> Bi + $^{0}_{-1}e$
10. Bi ----------> $^{214}_{84}\text{Po}$ + ______
11. $^{214}_{84}\text{Po}$ ----------> $^{210}_{82}\text{Pb}$ + ______
12. $^{210}_{82}\text{Pb}$ ----------> Bi + $^{0}_{-1}e$
13. ______ ----------> $^{210}_{84}\text{Po}$ + $^{0}_{-1}e$
14. $^{210}_{84}\text{Po}$ ----------> Pb + $^{4}_{2}\text{He}$
15. Are any isotopes of lead radioactive? ______________________

____

Paper and Pencil Exercise - 2
RADIOACTIVE DISINTEGRATION OF RADIUM-226

Complete the following decay chain of Radium-226:

1. $^{226}_{88}\mathrm{Ra}$ ----------> $^{222}\mathrm{Rn}$ + $^{4}_{2}\mathrm{He}$
2. ______ ----------> $^{218}_{84}\mathrm{Po}$ + ______
3. ______ ----------> Pb + $^{4}_{2}\mathrm{He}$
4. Pb ----------> Bi + $^{0}_{-1}\mathrm{e}$
5. ______ ----------> $^{210}_{81}\mathrm{Tl}$ + ______
6. $_{81}\mathrm{Tl}$ ----------> Pb + $^{0}_{-1}\mathrm{e}$
7. ______ ----------> $^{210}_{83}\mathrm{Bi}$ + ______
8. $_{83}\mathrm{Bi}$ ----------> Po + $^{0}_{-1}\mathrm{e}$
9. Po ----------> Pb + $^{4}_{2}\mathrm{He}$

COMPUTE YOUR OWN RADIATION DOSE

Paper and Pencil Exercise
--for the teacher-

Each student will determine how much radiation he or she receives in any one year from their activities. This exercise will help each student understand what is radioactive, the relative amounts of radiation from each source and whether the radiation is dangerous. Each student can also add in any other radiation received from other sources mentioned in the chapter.

Ask such questions as: Is an X-ray dangerous? (Answer -- No, relative dose is small). What are its benefits? (Answer -- early diagnosis of disease, fractures, etc.). Compare the amounts received to the 25,000 mrem/year amount necessary for noticeable physiological effects. Did the people around Three Mile Island (TMI) receive dangerous amounts of radiation? (Answer -- No, only 80 mrem, which is the same increase one would get by moving to Colorado from TMI).

Now study the paper and pencil exercise for the student which follows on the next page.

COMPUTE YOUR OWN RADIATION DOSE

Paper and Pencil Exercise

--for the student--

All organisms that inhabit the earth receive radiation. They get radiation from outer space, from soil and rocks, and from other organisms. We live in a sea of radiation, most of which is believed to do little or no harm to our body. This background radiation is very low, but it can be estimated.

The "rem" is a unit of radiation dose that indicates radiation effects on biological tissues. People working in occupations where they receive radiation as part of their work are permitted to receive up to 5 rems per year. Exposures of approximately 25 rems to the entire body is the minimum amount of radiation necessary to cause noticeable biological effects. Exposures from 400 to 500 rems over a short period of time to the entire body will result in death to 50% of the people receiving this amount of radiation.

The background radiation we receive is less than one rem per year. This amount is measured in millirems (mrem), which is .001 of a rem. It takes 1000 mrems to equal one rem. Everyone on earth receives on the average approximately 100-200 mrems per year. This natural background radiation comes from our own body, soil and rocks, and the atmosphere.

In the exercise below, compute your own radiation dose from the information given, keeping in mind the numbers are in millirems.

YOUR RADIATION DOSE
(in millirems per year)

Cosmic radiation at sea level, 30 mrem, add 1 mrem for every 100 ft. above sea level you live: ________

Your house or apartment, brick 75 mrem, stone 50, wood 25, and concrete 75: ________

Ground radiation, U.S. average: 30

Water, food, and air, U.S. average: 30

Nuclear weapons development and fallout: ________

Chest X-ray in the past year, add 20 mrem for each: ________

Dental X-ray in the past year, add 15 mrem for each: ________

For each 1,500 miles flown in a jet airplane in the past year, add 1 mrem: ________

Watching color TV, add 0.15 mrem for each hour of average daily use: ________

Living more than five miles from a nuclear plant, add 0 mrem: ________

Others: ________

____

YOUR TOTAL MREMS PER YEAR: __________

Your total mrems per yr. ________ ÷ 1000 = ________ rem per year.

PUBLIC OPINION POLL ON RISK

Paper and Pencil Exercise
--for the student--

PURPOSE

You will conduct a public opinion poll to determine the views of at least six individuals (preferably adults) concerning everyday hazards and nuclear power. Use the 25 items listed below in #1. Show the results on a sheet of paper, and hand it in along with your own personal opinion on this topic. Be prepared to discuss the results. Do the results indicate that the public is more fearful of nuclear power than its actual hazard would indicate? If so, what should be done to help people overcome this over-reaction?

Perform a similar survey for radiation hazards listed in #2 below.

What factors influence an individual's response to these items? Educational background (college degree or not)? Technical background? Liberal or conservative? Republican or Democrat? Rich or poor?

The actual observed or measured risks, along with the results from polls taken by various groups, are presented in Chart I.

PUBLIC OPINION POLL ON RISK

1. Consider the following activities. Beside each activity place a number indicating which activity is the most hazardous, the next hazardous, etc. The results will be numbered from #1, the most hazardous, to #25, the least hazardous.

Activity	Hazard Rating Number
smoking	________
alcoholic beverages	________
motor vehicles	________
handguns	________
electric power	________
motorcycles	________
swimming	________
surgery	________
X rays	________
railroads	________
general aviation	________
large construction	________
bicycles	________
hunting	________
home appliances	________
fire fighting	________
police work	________
birth control pills	________
commercial aviation	________
nuclear power	________
mountain climbing	________
power mowers	________
playing football	________
skiing	________
vaccinations	________

2. We all receive radiation from the following sources. For each source indicate whether the amount of radiation received is dangerous or not. Please check one answer for each source.

Source	Amount of Radiation			
	Dangerous	Somewhat Dangerous	Not Dangerous	Don't know or no opinion
Watching color TV	________	________	________	________
Home smoke detectors	________	________	________	________
Luminous watch dials	________	________	________	________
Chest X rays	________	________	________	________
Dental X rays	________	________	________	________
Nuclear weapons fallout (testing)	________	________	________	________
Brick building	________	________	________	________
Cross country air travel	________	________	________	________
Traveling on a wet highway	________	________	________	________
Using fertilizers	________	________	________	________
Gas lantern mantles	________	________	________	________
Wood building	________	________	________	________
Sleeping with your spouse	________	________	________	________
Natural gas stoves	________	________	________	________
Working in the US Capitol Building	________	________	________	________
Working in Grand Central Station	________	________	________	________
Living in Colorado	________	________	________	________
Living near a nuclear power plant	________	________	________	________
Living near Three Mile Island during and after the accident	________	________	________	________
Providing insulation and sealing the cracks in your home	________	________	________	________

Chart I

RANK AS PERCEIVED BY:

Rank	OBSERVED	Deaths per Year (USA)	League of Women Voters	College Students	Businessmen and Professionals
1	smoking	150,000	nuclear power	nuclear power	handguns
2	alcoholic beverages	100,000	motor vehicles	handguns	motorcycles
3	motor vehicles	50,000	handguns	smoking	motor vehicles
4	handguns	17,000	smoking	pesticides	smoking
5	electric power	14,000	motorcycles	motor vehicles	alcoholic beverages
6	motorcycles	3,000	alcoholic beverages	motorcycles	fire fighting
7	swimming	3,000	general aviation	alcoholic beverages	police work
8	surgery	2,800	police work	police work	nuclear power
9	x- rays	2,300	pesticides	birth control pills	surgery
10	railroads	1,950	surgery	fire fighting	hunting
11	general aviation	1,300	fire fighting	surgery	general aviation
12	large construction	1,000	large construction	food preservatives	mountain climbing
13	bicycles	1,000	hunting	spray cans	large construction
14	hunting	800	spray cans	large construction	bicycles
15	home appliances	200	mountain climbing	general aviation	pesticides
16	fire fighting	195	bicycles	commercial aviation	skiing
17	police work	160	commercial aviation	X rays	swimming
18	birth control pills	150	electric power	hunting	commercial aviation
19	commercial aviation	130	swimming	electric power	electric power
20	nuclear power	100	birth control. pills	food coloring	railroads
21	mountain climbing	30	skiing	prescription antibiotics	playing football
22	power mowers	24	X rays	mountain climbing	birth control pills
23	playing football	23	playing football	railroads	spray cans
24	skiing	18	railroads	bicycles	X rays
25	vaccinations	10	food preservatives	skiing	power mowers

CHAIN REACTION
Demonstration

PURPOSE

With a set of dominoes you can illustrate a chain reaction that occurs during nuclear fission of atomic nuclei. It is easy to arrange the domnoes in a standing position close to each other so when you knock one over the others fall.

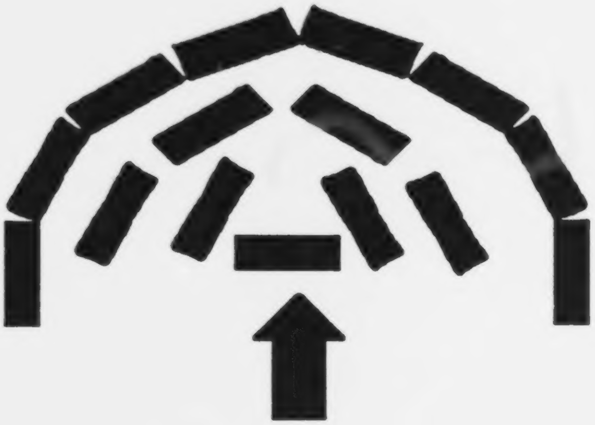


Diagram 1

MATERIALS

10 - 30 dominoes

PROCEDURE

Set up a row of dominoes on end and arrange them in a single line about one-half inch apart so that the face of one domino will be one-half inch from the back of the next domino. The dominoes will act as uranium-235 atoms. To initiate the chain reaction, tip the first domino in the line over. This will represent the first neutron striking the first atom of uranium. When an atom "splits", a part of it (neutron) is released and available to strike another successive atom or domino. This process is repeated with each successive domino in line.

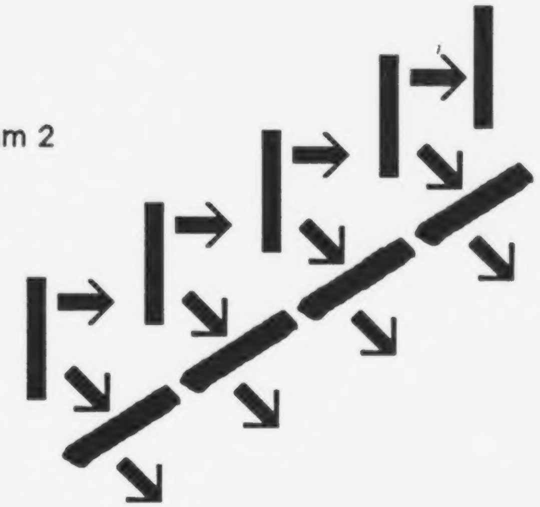
Now arrange the dominoes as shown in Diagrams 1. In this case, note that each block will fall and touch two more dominoes. This could represent the situation of a fissioning atom releasing two neutrons. In turn, the two falling dominoes tip over four more. Each falling domino results in more and more dominoes falling over in each successive row. This represents an uncontrolled chain reaction. But in a nuclear reactor, the fission reaction is controlled. Controlled means that only one domino ends up knocking down one other domino or that one neutron causes a fission and only one of the neutrons released from that fission causes another fission.

An interesting experiment is to time the rate at which the blocks fall in the case shown in Diagram 1. This time should be compared to the time required for the same number of dominoes to fall in the single line case. The rate should be slower for the single line, the controlled chain reaction case. Why? (Answer -- In the single line case, dominoes are falling one at a time. In the latter case, the number of dominoes falling simultaneously is continually increasing.)

One can model a slow-moving kind of chain reaction in another manner by setting up the dominoes as shown in Diagram 2. This type of chain reaction "wastes" some of the neutrons produced. In other words, some of the dominoes fall without hitting other dominoes. Since a falling domino represents a fission and thus an energy release, a slow-moving reaction releases energy slowly.

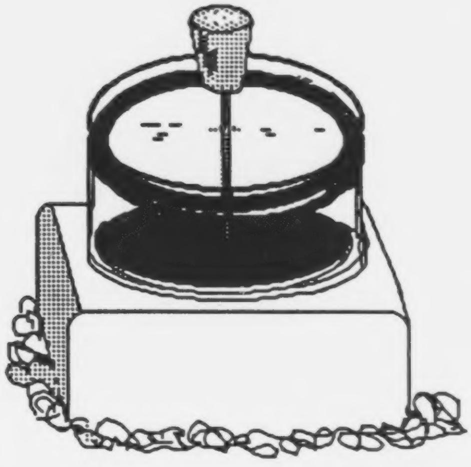
If you had billions of dominoes (representing billions of atoms), would it take very long for all of the dominoes to fall over if they were set up in a pattern, such as in Diagrams 1 and 2? Can you think of other ways of slowing down or controlling the chain reaction? (Answer -- Remove dominoes from certain places or locate a fixed wall between a row. This is analogous to placing a material near the uranium that absorbs or deflects the neutrons.)

Diagram 2



OBSERVING RADIOACTIVITY WITH A CLOUD CHAMBER

Demonstration



PURPOSE

A cloud chamber is a device that enables one to see the trails made by nuclear particles. It was invented in 1912 by Charles T. R. Wilson, a pioneer atomic physicist. Water vapor can condense on ions just as it does on bits of dust to form raindrops. Nuclear particles, such as alpha rays, produce ions as they streak through water vapor. The vapor that condenses on these ions shows up as fine white trails.

The experiment described here requires a radiation source. Suitable sources not exceeding the low radioactivity limits set by the U.S. Nuclear Regulatory Commission are available to the public.

Some inexpensive sources that do not require a license from the government and are "exempt" are available from The Nucleus Inc., Box 2561, Oak Ridge, Tennessee 37830. This company will provide an alpha ray source, containing polonium-210, designated as Po-210S, and a gamma ray source, containing cesium-137, designated as Cs-137-S-5. Mail order cost is $15 apiece.

Each is a solid source housed within a one-inch diameter thick plastic disc with identifying label. C-137-S-5 is completely sealed. But since sealing would block alpha rays, P-120-S is uncovered. Therefore the user is cautioned not to disturb the polonium-210 coating recessed within the disc.

These solid sources are considered to be safe. But as with chemicals and tools, radioactive materials should be respected and used with care. A brochure on proper handling techniques and safety precautions comes with the sources.

MATERIALS

A complete cloud chamber kit, including radioactive source, can be purchased from any of the main scientific supply companies for $10-15. It is much easier to use this prepared kit than to construct your own cloud chamber. Instructions are provided.

In addition to the kit, you will need a flashlight or high intensity lamp, rubbing alcohol, an eye dropper, and some dry ice.

Look up Dry Ice in your Yellow Pages telephone directory to find a dealer in your area, or you may be able to obtain some from your school or local dairy. You need a piece about four inches by four inches by one inch (roughly one-half pound in weight). Dry ice is frozen carbon dioxide. It is cold enough to cause severe burns to unprotected skin and must be handled very carefully. Wrap the dry ice in a towel; never touch the exposed ice. For safety's sake, it is a good idea to wear leather gloves when you handle the block. Tongs are also recommended.

PROCEDURE

1. Pour a thin layer of alcohol on the bottom of the chamber and on the blotter paper around the sides. The eye dropper is useful here.

2. Place the chamber on the dry ice.

3. After the chamber has cooled for five minutes, darken the room and shine a flashlight through the side of the chamber.

The air layer near the bottom of the chamber is supersaturated with alcohol vapor. There is more vapor in the air than usual and at this low temperature the gas will form liquid droplets whenever it is disturbed. Dust in the chamber will cause mist to fall to the bottom of the chamber during the first half-hour.

The tracks formed by the radiation appear to be white lines in the cloud. As the radiation passes through the atmosphere inside the chamber it knocks electrons off of the atoms in the air. The alcohol vapor then condenses on these charged particles making their paths visible in the chamber.

Most of the tracks will be about one-half inch long and quite sharp. These are made by alpha radiation since this radiation has a greater charge and will attract more alcohol vapor.

The longer, thinner tracks are made by beta radiation since this type of radiation has a smaller charge and will attract less alcohol vapor.

Twisting, circling tracks that are very faint and difficult to see are caused by gamma radiation.

4. Mark the top of the chamber at the point where the alpha tracks disappear. Measure how far that radiation traveled from the source. Now measure the length of the beta tracks from the source. Compare the two lengths. Next, hold the north end of a strong magnet close to the chamber. Note the effect on the alpha tracks? What is the effect on the beta and the alpha tracks? (Answer -- Since beta and alpha radiation are charged particles, they will be affected by the magnetic field and will deviate from their straight line paths). Wrap the source in a sheet of paper. Which types of radiation are still visible? (Answer -- Alpha rays will not penetrate the paper. Placing material between the radiation source and another object, such as yourself, shields the object from the radiation, since not all of the radiation will penetrate the shield. Add several more sheets of paper and the beta particles will be stopped also, leaving only the gamma rays to make trails.

5. Do you see radiation in the cloud chamber? (Answer -- No - you see the tracks that the radiation makes through the vapor).

RADIOACTIVE HALF-LIFE

Laboratory Exercise

--for the teacher--

PURPOSE

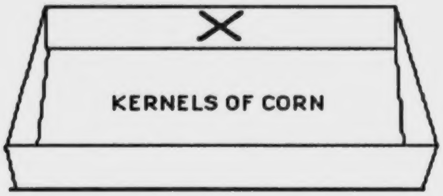
The purpose of this laboratory is to help students understand the principles underlying radioactive half-life. The laws of chance are also illustrated. Radioactive decay is a random process similar to tossing a coin. To illustrate this concept, we need an experiment involving a test in which there are only two outcomes.

MATERIALS

14-boxes -- shallow square cardboard boxes with covers (approximately 5 x 5 inches). You can make square boxes from rectangular ones by cutting off the long dimension and restoring the sides with tape.
Popcorn -- approximately one pound of unpopped kernels of corn
Felt-tip pen
14-sheets of graph paper

With 14 boxes you can accommodate 28 students working in pairs. One hundred pieces of corn will be placed into each box. You can facilitate the preparation of this lab by asking a few students to help you count out the 100 pieces of corn for each box. A simple way to do this is to arrange the corn in rows and columns of ten, producing a 10 x10 matrix, making it easy to see when you have 100 pieces of corn.

The boxes can be obtained at department stores, gift stores, or box stores. Place an **X** on one of the inside walls of the box. Place a rubber band around each box so the cover does not come off and corn is spilled all over. You may want to line the boxes with felt to reduce the noise and hold the kernels in place while they are being removed.



PRELABORATORY DISCUSSION

Review some basic concepts related to radioactive decay with students.

What happens when a radioactive element decays?

Answer -- The nucleus of the element gives off rays or particles. In some instances this release of matter and energy changes the mass of the element by reducing the number of protons and neutrons in the nucleus, forming a new element with a lower atomic mass (A). In other instances it results in the transformation of a neutron into a proton, increasing the atomic number by one (B).

A.	${}^{226}_{88}\mathrm{Ra}$ radium	---------->	${}^{222}_{86}\mathrm{Rn}$ radon	+	${}^{4}_{2}\mathrm{He}$ alpha particle
B.	${}^{210}_{83}\mathrm{Bi}$ bismuth	---------->	${}^{210}_{84}\mathrm{Po}$ polonium	+	${}^{0}_{-1}\mathrm{e}$ beta particle

When a neutron transforms, it forms a proton and an electron which is called a beta particle. Yes, it is strange to have a situation where energy and matter are given off, yet you end up with an element which has a greater atomic number--another unusual facet of nature. Even more unusual is that sometimes a new element will appear (A and B) as the number of protons in the nucleus changes.

Be sure to spend plenty of time on this because it is often a difficult idea for students to grasp. Call on many students to respond and be sure to give them time to think, and to respond orally and on paper. This is where you must be a thorough instructor.

Why are some elements unstable and decay?

Answer -- When elements have too many particles or neutrons versus protons in their nucleus, they have an abundance of energy in their nucleus. This excess energy causes the atom to be unstable and give up energy in the form of particles so that it can stabilize. Remember, everything in nature wants to become stable.

How can you tell if a substance is radioactive?

Answer -- Radioactive substances give off particles, rays, or energy that can be detected and measured accurately.

What is half-life?

Answer -- Since a radioactive isotope is constantly changing into something else, a very useful question is how long will the isotope last before all the atoms in it have changed to something else. Half-life is the **time it takes for one-half of the radioactivity** to be given up. One way to tell how many atoms of a radioactive isotope are left is to use an instrument, such as a Geiger counter, that measures radioactivity by measuring the number of alpha, beta, or gamma rays emitted. Generally, the less radioactive material there is, the weaker the radioactivity will be.

Why do radioactive substances behave this way?

Answer -- Whether an atom is going to decay or not in the next second is a matter of chance. It might decay now, or it might not decay for another million years. As with flipping a coin, there are only two possible outcomes, the atom either decays or it doesn't. The chances that an atom will decay in the next second are a lot greater with an isotope that has a short half-life than one with a long half-life.

How can you illustrate 50-50 chance occurrence?

Answer -- Take a coin and flip it many times, each time recording whether a head or tail appears. What is the chance of getting a head or a tail? If you flip the coin only ten times what do you get? Flip the coin 30 or 40 times and you will find that the 50-50 probability becomes truer and truer. Radioactive decay is a similar process.

Tell the students that they are going to perform a half-life laboratory activity using kernels of corn. Each box has 100 kernels of corn. Go over the procedure listed below before you permit students to begin the activity.

PROCEDURE

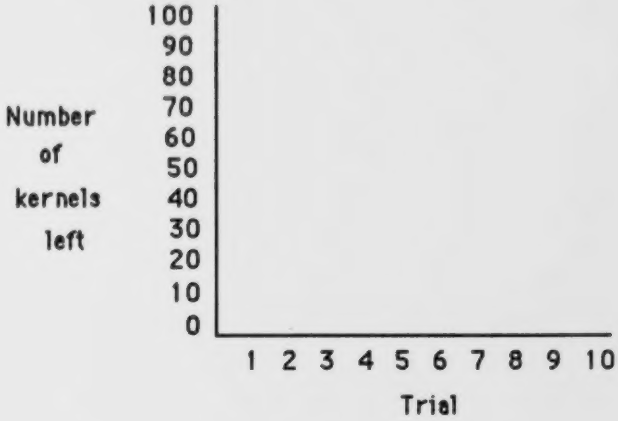
1. Pass out the boxes, each with 100 kernels of corn in it. Note that each kernel of corn has a pointed end. When the corn is in the box, the pointed end will point to one of the four sides of the box. What are the chances of a particular kernel pointing to the side marked X?
(Answer -- 1 in 4).

2. With the cover securely on the box, shake it five or six times. Place the box on the table and remove the cover.
3. Remove the kernels that are pointing to the **side with the X.** Remember the kernels can be pointing to any part of the side with the X, not just directly at the X. If some of the kernels are pointing exactly at the X-side's corners, take one-half of those out. **Do not put** any of the kernels back into the box.
4. Record the number of kernels taken out and the number left. Do this for ten trials.

DATA TABLE FOR HALF-LIFE GRAPH

Trial	Started with	Took out	Number left
1.	100		
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

5. After the ten trials, graph the results: number of kernels left versus trials. Ask the students to label axes of the graph; they need practice in this skill. Connect the points with a smooth line rather than using a ruler.
6. Use the figures from the class totals to construct a composite graph on the chalkboard from everyone's results.



POSTLABORATORY DISCUSSION

1. Call on many groups of students to hold up their half-life graphs and compare the curves. Discuss the variation in the graphs. Point out that this is not due to students' errors, but to the fact that the smaller the sample, the more the variation. Note that the composite curve from everyone's results is generally smoother since the number of trials is greater on this curve than on any individual group's curve. In an experiment measuring the radioactivity of actual materials, the curve would be very smooth, since the sample of material would contain millions and millions of atoms.

2. Ask why a curved line was obtained instead of a straight line?

Answer -- When you take one-half of something you get something even though it may be very small. In other words, you just do not end up with nothing quickly.

3. Define half-life.

Answer -- The time it takes for one-half of the radioactive atoms to disintegrate.

4. During radioactive decay, when does an element decrease its atomic number? Increase it?

Answer -- When the nucleus of an element gives up an alpha particle it loses four atomic mass units--two protons and two neutrons--it forms a lighter element. When one of the neutrons transforms into a proton and a beta particle it forms a new element with a larger atomic number. See the example given earlier.

5. What is the significance of a long half-life versus a short half-life?

Answer -- An element with a long half-life gives off matter/energy slowly; therefore its radioactivity is not very intense. Consequently, it is generally not very dangerous but will be around a long time as a radioactive element. An element with a short half-life gives off matter/energy very quickly therefore its radioactivity is intense. It will not be around as long, but it may be very dangerous because of the rate at which it gives off radioactivity.

6. How many trials did it take to use up half the kernels?

Answer -- Usually between 2 and 3.

7. How many trials did it take to use up half of the 50 that were left?

Answer -- Usually between 4 and 5.

RADIOACTIVE HALF-LIFE

Laboratory Exercise

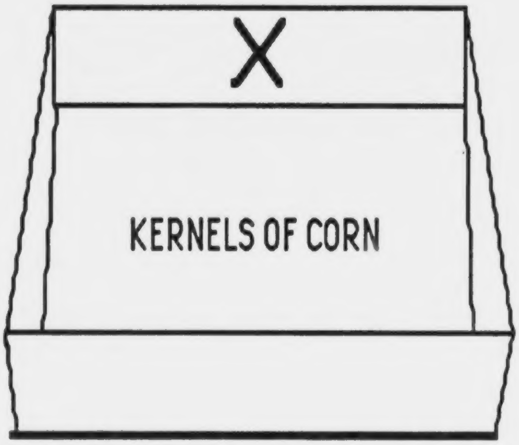
--for the student--

PURPOSE

The purpose of this laboratory exercise is to help you understand the principles underlying half-life. Radioactive decay is a random process similar to that of tossing a coin. To illustrate this concept, we need an experiment involving a test where there are only two outcomes.

MATERIALS

One box with 100 kernels of corn
A sheet of graph paper



PROCEDURE

1. With the **cover securely on the box** of corn kernels, shake it five or six times. Place the box on the table or desk and remove the cover.

2. Remove the kernels that are pointing to **any part of the side with the X.** The kernels that you remove can be pointing to any part of the side with the X, not just directly at the X. If some of the kernels are pointed exactly at the X-side's corners, take one-half of those out. Do not put any of the kernels taken out back into the box.

3. Record the number of kernels taken out and the number left. Do this for ten trials and record your data on the table below.

DATA TABLE FOR HALF-LIFE GRAPH

Trial	Started with	Took out	Number left
1	100		
2			
3			
4			
5			
6			
7			
8			
9			
10			

4. After ten trials of shaking the box and removing kernels of corn, graph the results: number of kernels of corn left in the box versus trials . Label your graph accurately and completely, even title the graph. Connect the points with a smooth line rather than using a ruler.

CONCLUSION

1. Describe the appearance of your graph.

2. Define half-life.

3. What is the half-life of the "element" (kernels of corn in this instance) you are working with? (number of trials).

Safety in the Laboratory

8

Every year numerous accidents occur on school campuses. Some of the accidents occur in science laboratories. In 1977-78, according to the 1981 edition of the National Safety Council publication Accident Facts, approximately 14% science related accidents occurred. The highest number of occurrences was in grades 7-9. With more students taking activity-centered science courses, the number of accidents may be expected to increase. It becomes more necessary for science teachers to be aware of the legal responsibilities with regard to safety in the laboratory. In recent years the number of liability suits filed against science teachers has increased. Probably the best way for teachers to operate a science laboratory and reduce the chances of being sued is to practice risk management. Risk management is the systematic attempt to reduce exposure to liability by assessing the risks and controlling them.

All science laboratories are sites of potential danger for both students and teacher; this is especially true of physical science because of the chemicals, apparatus, and equipment used. There are four areas of the science laboratory where science teachers must take special preventive measures in order to avoid accidents, such as students being burned, cut, or poisoned, which would result in liability suits. These areas are laboratory security, safety instructions, appropriate facilities, and protective equipment.

With the trend of science programs toward increased hands-on activities by students, it is more important than ever before for each school to have a laboratory safety program. Safety must be considered when planning, preparing, and implementing a science program and when planning, preparing, and teaching a science lesson. The laboratory safety program should include general safety rules, information about chemical hazards, evacuation and first-aid procedures, the use and operation of safety equipment, and training for science teachers and students.

Student safety training is the direct responsibility of the teacher in charge of the course. In developing and implementing the safety training program for their students, each science teacher should:

1. Compile a set of safety rules and present them to their students.
2. Instruct their students in generic safety procedure.
3. Instruct their students in specific safety procedures for the course they are teaching.
4. Post the safety rules in the classroom and the laboratory.
5. Discuss the rules with the students on a regular basis.
6. Require students to sign a Safety Contract after they pass a safety test (See Table 4).
7. Plan, prepare, and present laboratory activities with safety in mind.
8. Rehearse emergency procedures with students.
9. Post emergency instructions concerning fire, explosions, chemical reactions, spills, and first-aid procedures near all storage areas.

This section of the manual is a compilation of recommended practices and suggestions for making science classroom and laboratories safer places for teachers to teach and students to learn. It is not intended to be a complete guide to safety. It is intended to provide basic guidelines for safe practices in physical science classrooms and laboratories. It includes a list of physical science laboratory facilities and safety equipment, general safety guidelines, a student guide to safety, information about chemical storage and disposal, guidelines for laboratory assistants and suggestions for safe field experiences. A Paper and Pencil Quiz on safety is also included at the end of the chapter. It is strongly recommended that you consult the list of references and other printed materials and audiovisuals on safety for additional guidelines for safe practices.

SCIENCE LABORATORY FACILITIES AND SAFETY EQUIPMENT

Physical science teachers must always remember that science laboratories are places where accidents commonly occur. Accidents are often caused by improper supervision of students, faulty laboratory techniques, poor housekeeping, failure to practice proper safety procedures and lack of safety equipment. Remember, it is the teacher's responsibility to prevent accidents and assure that the laboratory is as safe as possible. This includes setting a good example for students by following all safety rules and regulations. We cannot overlook the fact that a safe laboratory must begin with the physical facilities. When physical science laboratories are built or remodeled, the following physical facilities are needed for a safe learning environment.

Adequate lighting and heating
Adequate space for conducting experiments
Two unobstructed doors to the laboratory
Master shut-offs for gas, water, electricity, and other services
Grounded electrical outlets
Safety shower
Fume hood and/or exhaust fans
Adequate space and security for storage of chemicals and supplies
Proper storage cabinets for storing chemicals
Surfaces of furniture treated to reduce combustibility
Rimguard shelves in storage areas
Wide aisles and exit passages

In addition to the physical facilities, the laboratory should also include safety equipment appropriate for the type of physical science activities to be conducted. Protective equipment is designed to prevent or minimize injury; it does not prevent accidents from occurring. The protective equipment provided should include:
Safety goggles
Sterilizer for the safety goggles
First-aid kits
Fire extinguishers
Eyewash facilities
Laboratory aprons
Fire blankets
Sand buckets

Fire extinguishers

The multipurpose ABC-type dry chemical fire extinguisher covers Class A, Class B, and Class C fires. Fires resulting from reactive and combustible metals such as sodium, lithium, potassium, magnesium, and certain metallic hydrides and alkyds require a special extinguisher powder. Unlike regular dry chemical and general purpose dry chemical, it is applied with a scoop. Dry sand may also be used to extinguish these Class D fires. Apply sand by scoop.

CLASSIFICATION OF FIRES

Class A - Fires in textiles, wood, and other ordinary combustibles containing carbonaceous material. This type of fire is extinguished by cooling with water or a solution containing water (loaded steam) which wets down the material and prevents the glowing embers from re-igniting.

Class B - Fires in gasoline, oil, paint, grease, or other flammable liquids that gasify when heated. This type of fire is extinguished by shutting off the air supply.

Class C - Fires in live electrical equipment. This type of fire is extinguished by using a nonconducting agent. Whenever possible, the source of power to the burning equipment should be cut off.

Class D - As stated earlier, this classification of fires includes combustible metals such as magnesium, sodium, potassium, and others.

TABLE 1

CLASS OF FIRE	TYPE OF EXTINGUISHER(S)
A	GENERAL PURPOSE DRY CHEMICAL
B	CARBON DIOXIDE; DRY CHEMICAL; FOAM
C	DRY CHEMICAL; CARBON DIOXIDE
D	SPECIAL EXTINGUISHER POWDER; DRY SAND

FIRST-AID KIT REQUIREMENTS

A first-aid kit should be large enough to hold the proper contents for the physical science laboratory. Its contents should be arranged so that the desired package can be found quickly without unpacking the entire contents. The materials should be wrapped so that unused portions do not become dirty through handling. It is suggested that a first-aid kit should include:

- Bandages (different sizes)
- Sterile gauze
- Alcohol
- Burn ointment
- Tweezers
- Boric acid
- Tape
- Antiseptics
- Cotton
- Ampules of ammonia
- Scissors
- Bicarbonate of soda
- Gauze roller bandage

General Safety Guidelines

Although a variety of federal, state, and local laws have been written in recent years to protect our health and safety, only well informed science teachers exercising good judgement will ultimately provide a safe learning environment for students. In addition to the components of a safety training program for students, science teachers should practice the following guidelines. These guidelines can be used as an effective checklist for evaluating the science safety program.

1. Always perform an experiment or demonstration prior to allowing students to perform the activity. Look for possible hazards. Alert students to potential dangers.
2. Give safety instructions to students before an experiment begins.
3. Students should perform no unauthorized experiments.
4. Constant surveillance and supervision of student activities are essential.
5. Student attitudes toward safety is imperative. Students should not fear doing experiments, using equipment or reagents, but should be taught to respect them for potential hazards.
6. Teachers should set good safety examples when conducting demonstrations and experiments.
7. Laboratory activities should never be assumed to be accident free.
8. Frequent inspection of the laboratory should be conducted.
9. An annual safety check of each laboratory should be conducted.
10. Have first-aid procedures established in the event of an accident.
11. All students and teachers should know the location of fire extinguishers, eyewash fountains, first-aid kits, and other safety equipment.
12. Safety signs should identify the location of safety equipment.

13. Safety posters should be placed in science laboratories.
14. Always check to be sure supplies and equipment from an experiment are returned to the proper place.
15. Stress correct usage of supplies and equipment to the students.
16. Teachers are personally responsible for requiring all students to wear regulation safety glasses (goggles) during experiments.

Specific Safety Precaution

1. Keep aluminum foil available to place under candles so melted paraffin does not get on the tables.
2. Provide containers for matches, solid wastes, and broken glassware. Never allow students to leave matches and other trash on the floor and certainly not in the sinks.
3. Use ceramic squares for hot objects.
4. Liquids or solids found in unlabeled containers should be discarded. Do not guess as to the nature of the substance.
5. At the beginning of any experiment, if there are any special hazards, instruct students regarding the recognition of dangers and the precautions to be taken.
6. Wire gauze should separate a flame from glassware. Never apply heat directly to glassware as even pyrex will break or shatter if a Bunsen burner flame is allowed to remain at one given place too long. The wire gauze will evenly distribute the heat to the glass container.
7. Students should never be allowed to insert nor remove thermometers from rubber stoppers. The teacher should insert the thermometers into the correct size rubber stoppers and leave them in the stoppers as they will be needed for other classes and for other experiments. Split rubber stoppers may be used.
8. When inserting barometer tubes, convection tubes, or other glassware into a clamp, use either a split rubber support or split rubber tubing around the glass tubing to separate the glassware from the clamp.
9. In performing experiments where there is a possibility of spattering, where there is the slightest chance of a serious flash or explosion, or where you deliberately use mixtures with the intent to explode them, the following precautions should be observed:
    a. Keep students at a distance not less than 2.5 meters from the demonstration table.
    b. Use a screen of strong, fine, wire mesh, glass, or other suitable device as a shielding for both students and teacher.
    c. Whenever possible, glass vessels wherein explosions may take place should be made "shatterproof" by cementing several layers of cellophane onto the glass with collodion. This will provide safety without affecting visibility.
10. All reagent bottles should be prominently and accurately labeled.

SAFETY GUIDE FOR STUDENTS

Accidents do not just happen -- they are caused. Many accidents have occurred when students failed to use common sense, failed to follow instructions, displayed an indifferent attitude, or were careless. Students should be aware of what their classmates are doing. They should be taught not to hesitate to comment to other students about unsafe acts and/or to report unsafe behavior to the teacher. Only lab instructions and lab notebooks should be permitted in the working area. Books, purses, and other items should be placed in desks or storage area. There should be a limited number of general rules for the laboratory, but they must be rigidly and impartially enforced. The guidelines listed under Laboratory Safety should be included in your safety training program.

General

1. Students must wear regulation safety goggles at all times in the laboratory and where chemicals are stored and handled.
2. Eating and drinking in the laboratory are not allowed.
3. Unauthorized experiments are prohibited.
4. Never perform experimental work when alone in the laboratory.
5. Horseplay, pranks, or other acts of mischief are prohibited.
6. Follow all safety instructions carefully.
7. Never taste or touch chemicals with the hands unless specifically instructed to do so. Wash hands before leaving the lab.
8. Know the location of and how to use safety equipment (fire extinguishers, etc.).
9. Keep the working area clean including the table top, floor, sink, sink counters.
10. Report at once, to the teacher in charge, any personal injury sustained, no matter how trivial it may appear, whether a cut, burn, scratch, or corrosive liquid on the skin.

Laboratory Safety

11. Pour liquids from a bottle without spilling the contents on the hands, desk or floor. Hold glass stoppers between the fingers with the moist portion away from the hand.
12. Never pour reagents back into the bottles, or exchange stoppers of bottles, or lay a stopper on the desk.
13. Don't pour water in acid. (Do What You "oughta", Put The Acid In The Water!)
14. In laboratory work involving test tube heating, never look down into the test tube while heating it or point the mouth of the test tube in the direction of any person.
15. Exercise caution when heating liquids in soft glass test tubes to avoid possible injury. The test tube will probably break if not thoroughly dry on the outside or if the flame is concentrated at one spot for any length of time.
16. When required to heat a substance in a glass vessel, always apply the heat slowly. In the case of heating in a test tube, move the test tube in the flame so that it is heated evenly. This will avoid overheating a single area and prevent glass breakage and possible injury.
17. Broken or chipped glassware should not be used.
18. Confine long hair and loose clothing. Laboratory aprons should be worn.
19. In experiments involving the use of concentrated acids, observe the following precautions:
    a. Immediately wash with water any part of the skin that has been in contact with strong acid or with alkali. (This is the best emergency treatment.)
    b. Hydrochloric acid should be used instead of sulfuric acid in all possible cases. The volatility of the former makes it less harmful to clothing and skin. In addition, it is less corrosive.
20. On inserting glass tubing into rubber stoppers, corks or tubing, observe the following precautions:
    a. Use water, soap solution, glycerin or vaseline as a lubricant before inserting the tube into the hole with a twisting motion.
    b. Always aim the glass tubing away from the palm of the hand which holds the stopper, cork or rubber tubing.

c. Always hold the tubing as close as possible to the part where it is entering the rubber stopper.
d. Using a cloth wrapped around the hand or the tubing at the point of contact with the hand will help avoid injury if the glass breaks.

21. Put matches and other solid wastes in the containers provided. Pour liquids into the sink with adequate flushing of water. Remember that some hot liquid wastes will solidify and clog up a drain just as readily as matches, filter paper, etc.
22. Remember to put glassware where it cannot be accidentally knocked off nor tipped over.
23. Use a cloth, pot holder, or clamp to pick up hot bottles and flasks. Test tube holders and tongs do not furnish a grasp secure enough to hold a flask. Remember that hot glass does not look different from cool glass and should not be picked up with a bare hand.
24. Make sure electrical cords and the insulation on electrical wires are not frayed.
25. Know the total voltage of electricity before using a piece of electrical equipment.
26. Do not touch current carrying wires that are not insulated and do not let them touch each other.
27. Never handle electrical equipment with wet hands or when standing in damp areas.

CHEMICAL STORAGE AND USAGE

Accidents (burns, injuries, and poisonings) due to chemicals, electrical devices, gas outlets, specialized equipment such as Bunsen burners and lasers, are not uncommon in the physical science laboratory. Many accidents can be prevented by exercising good judgement. Exercising good judgement should begin with the procurement of equipment and supplies. This is especially true when purchasing chemicals. Chemicals should be properly packaged and labeled. Only the quantities needed for the instructional program for a school year (one semester for hazardous chemicals), should be purchased.

Storage

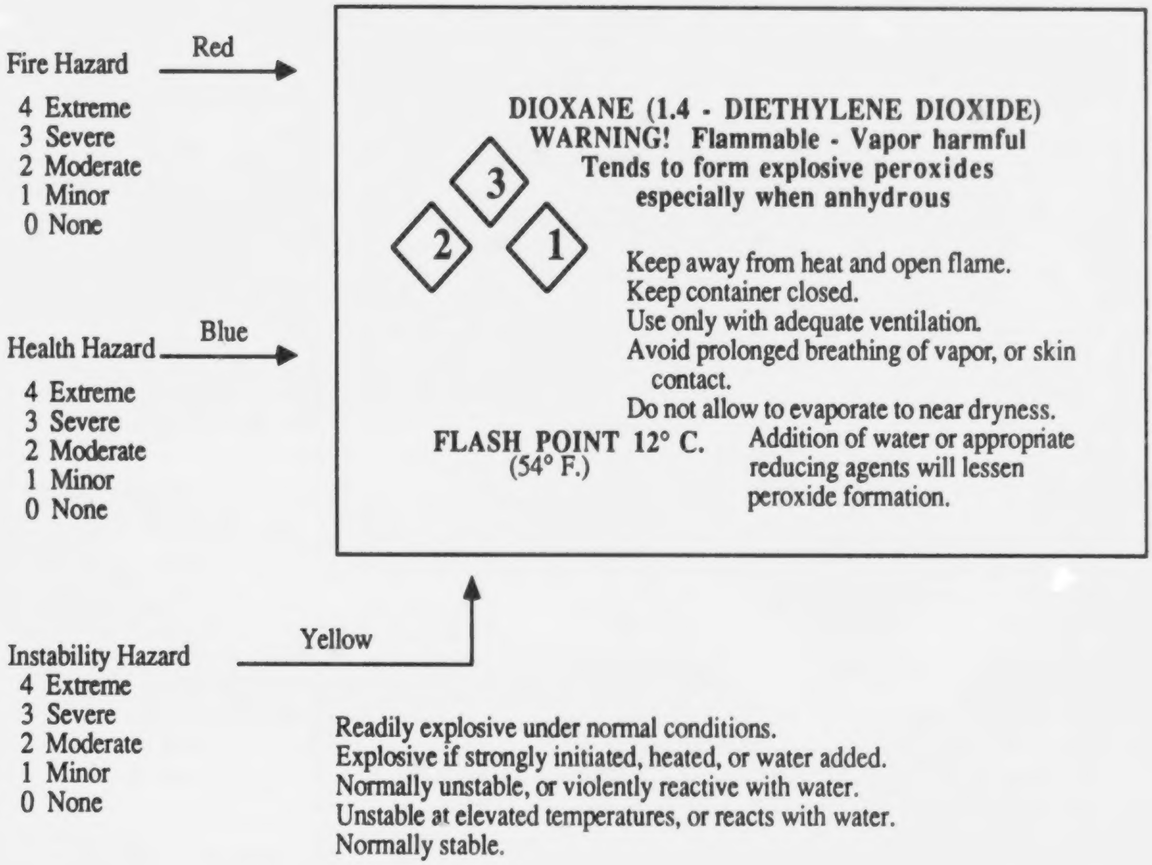
Proper storage of equipment, supplies, and chemicals is essential to the safe operation of the physical science laboratory. Precautions should be taken when storing all equipment, supplies, and chemicals. However, due to the wide variety of chemicals used, extra precautions must be taken in storing them. Laboratory chemicals and equipment should not be stored in the same area. If possible, a separate room should be used for chemical storage. Chemical storage areas should be clean, orderly, free from blind alleys, well ventilated and lighted.

Chemicals should not be kept on crowded shelves. The shelves should be deep enough so that the chemicals will not become easily dislodged. Shelves with a rim guard are preferred over shelves without a rim guard and low level storage is preferred over high level storage. Periodic on-site inspections of chemical storeroom facilities should be made.

It is essential to label both the storage areas (shelves, etc.) where the equipment and supplies are stored and also the individual items. The container of small items, such as rubber stoppers, may be labeled instead of each individual item.

The labeling of chemical containers is a must for the safe operations of a science laboratory. Proper labeling can reduce the potential for accidents happening that result in personal injury due to misuse, mistakes, spills, etc.

Chemical labels should contain the name of the chemical, the chemical formula, degree of hazard (DANGER, WARNING, CAUTION), statement of hazard (POISON, CAUSES BURNS, etc.), precautionary measures (KEEP AWAY FROM HEAT, DO NOT GET IN EYES, etc.), and instructions in case of contact or exposure. Figure 1 is an example of a label that is available through several scientific supply companies. Table 2 gives an approved storage arrangement for chemicals and Table 3 lists incompatible chemicals.



Fire Hazard
4 Extreme
3 Severe
2 Moderate
1 Minor
0 None

Health Hazard
4 Extreme
3 Severe
2 Moderate
1 Minor
0 None

DIOXANE (1.4 - DIETHYLENE DIOXIDE)
WARNING! Flammable - Vapor harmful
Tends to form explosive peroxides
especially when anhydrous

Keep away from heat and open flame.
Keep container closed.
Use only with adequate ventilation.
Avoid prolonged breathing of vapor, or skin contact.
Do not allow to evaporate to near dryness.

FLASH POINT 12° C.
(54° F.)

Addition of water or appropriate reducing agents will lessen peroxide formation.

Instability Hazard	
4 Extreme	Readily explosive under normal conditions.
3 Severe	Explosive if strongly initiated, heated, or water added.
2 Moderate	Normally unstable, or violently reactive with water.
1 Minor	Unstable at elevated temperatures, or reacts with water.
0 None	Normally stable.

Figure 1

Safety in the Secondary Science Classroom NSTA

Note to the Teacher

In 1971, Congress signed into law the Occupational Safety and Health Act (OSHA). The Act, primarily an environmental law, has had positive effects on improving working conditions in industrial settings as well as schools. Since 1971, many states have written Right to Know Laws modeled after OSHA regulations. In general, these laws say that employees have a right to know about hazardous chemicals with which they work, their effects and how to protect themselves from the chemicals. Most Right to Know Laws include the following components -- substance identification, use of Material Safety Data Sheets, requirements of chemical labels, employees training, and record keeping.

Important information concerning the storage and disposal of a chemical is included on the Material Safety Data Sheets (MSDS) for that chemical. These forms come in different formats but all include the following information.

1. Identifiers: chemical name, formula, synonyms, molecular weight (mass)
2. Hazardous ingredients, if applicable
3. Precautionary measures (Caution, Warning, Danger, etc.)
4. Emergency first aid procedures
5. Physical Data (B.P., M.P., etc.)
6. Fire and explosion information
7. Reactivity data (stable, unstable, incompatibilities, etc.)
8. Spill and leak procedures
9. Health hazard data (first aid, etc.)
10. Occupational Control Measures
11. Storage and other special information

Check with one of the ten regional or 121 area offices of OSHA to find out about the law and how it affects the science program in your state/district.

Chemical Disposal

Waste materials accumulate not only as a natural byproduct of scientific investigations, but also because chemicals are no longer used or needed, have aged and become useless for the intended purpose, or are in containers that are not properly labeled. Only the quantities needed for the instructional program for a school year (one semester for hazardous chemicals) should be purchased.

Disposal of chemicals requires careful planning. Before chemicals are disposed of, three major aspects of the problem must be considered - federal, state, and local rules and regulations, the effect on the environment, and the toxicity/hazard of the chemicals.

There are a number of options for disposal of chemical wastes. Generally, the options available for schools to select from are:

1. Return unused chemicals to the supplier.
2. Dispose of materials in an incinerator.
3. Contract with a commercial firm to dispose of the wastes.
4. Destroy the hazardous characteristics of the wastes through chemical reaction (neutralization, dilution).
5. Dispose of wastes in a landfill.

Before an option is selected, be sure to consider the three major aspects of chemical disposal listed above. The Laboratory Waste Disposal Manual, published by the Manufacturing Chemists Association, should cover the disposal procedures for most chemicals found in the physical science laboratory.

Instructions for disposal of chemical wastes produced as a result of laboratory investigations should be given to the students as a part of the pre-laboratory preparation. Disposal procedures should be written and distributed to the students. Interpretation and use of disposal procedures should be a part of the safety training program.

STUDENT LABORATORY ASSISTANTS

Some schools use student laboratory assistants to help teachers prepare for laboratory sessions. If students are used as laboratory assistants, special attention must be given to supervising and training them. Due to the potential hazards prevalent, laboratory assistants should be under the direction of a teacher and never allowed to work alone in the science storeroom/preparation area.

Student assistants should be carefully selected and thoroughly trained and directed in safe laboratory techniques. After training, they should be tested over the techniques and required to sign a Safety Contract (see Table 4) similar to the contract students should sign after their safety training. Students should have successfully completed the course(s) in which they act as assistants. Assistants should be given written instructions on specific duties and operations for which they are responsible. If assistants are required to prepare stock solutions and/or dispense chemicals, specific instructions could be placed on index file cards for them. A color-coded system could be established to indicate the degree of the hazards (fire, health, and instability) involved. Include procedures to follow in case of a mishap on the back of the card.

The National Science Teachers Association (NSTA) lists the following specific rules for laboratory assistants in its publication Safety in the Secondary Science Classroom.

1. Act under the direct supervision of a teacher at all times and in all places.
2. Do not carry laboratory equipment or apparatus through the hall during the intervals when classes are passing.
3. Do not transport dangerous chemicals at any time (concentrated acids, bases) unless under the direction of a teacher. They should be transported in proper containers of at least two times the capacity of the containing unit.
4. Do not handle materials on the demonstration desk unless authorized to do so.
5. Do not taste chemicals or other materials.

Once you have selected your laboratory assistants, the next step is training them before they are permitted to carry out their responsibilities. Your training could include information about the following:

1. Preparing laboratory materials and setups
2. Disposing of laboratory wastes.
3. Cleaning up the laboratory and storage/preparation areas
4. Stocking and restocking lab stations and/or storerooms
5. Practicing safety and first-aid procedures
6. Operating equipment
7. Taking inventory of lab equipment and supplies

Duties of laboratory assistants must be clearly defined. Assistants should have a full schedule of tasks to perform. Back-up projects (studying, tutoring, etc.) should be ready just in case they complete their assigned tasks.

Be sure to provide a place for the assistants to work and to store their books and other personal items.

FIELD EXPERIENCES

Field trips and investigations are an essential part of the science curriculum. Field trips and investigations can be valuable teaching/learning experiences for teachers and students. In order to make them so, careful planning is required. A poorly planned field experience can be a waste of time and even worse than no experience at all. In addition to having well-stated instructional objectives, every precaution must be taken to assure the safety of students and teaching personnel.

Pretrip/investigation preparations and follow-up (posttrip) activities and discussions should be included in the plans. The following list of general safety guidelines can make a field trip/investigation safer and more effective as a teaching strategy.

1. Establish rules for safe conduct prior to a field experience.
2. Have adequate adult supervision for the class size. Suggested ratios: 1to 30 for a "controlled" field experience; 1 to 5 for an "uncontrolled" field experience.
3. Decide on the seating and/or group arrangement to be used prior to the experience. This should not be done after the students arrive at the site of the field experience. Students should be grouped for ease of identification and control. Suggested group size: Four students for a "controlled" field experience; two to four students for an "uncontrolled" field experience.
4. Obtain proper consent, according to school and district policies prior to any field experience. This may include parental and/or administrative consent.
5. Have a large trash bag for each bus if you are traveling by bus. Decide if travel will interfere with a meal time. If so, include a food stop or allow students to take a lunch to be eaten on the bus to or from the field site.
6. Check roll each time the students load the bus(es). Check roll before the presentation starts or after the students reassemble if they are separated into groups during the field experience.
7. Separate potential problem students.
8. Do not leave the students unsupervised at any time during the field experience. Supervision is necessary for proper conduct and safety. Teachers should position themselves in different parts of a controlled group for adequate supervision.
9. Advise students of proper clothing and necessary equipment and supplies needed for the field experience.
10. Have a first-aid kit readily available.

* Controlled Group - Students stay together for the activity.
Uncontrolled Group - Students divide into two or more groups for the activity.

TABLE 2
SUGGESTED CHEMICAL STORAGE PATTERN

INORGANIC	ORGANIC
1. Metals, hydrides	1. Acids, anhydrides, peracids
2. Halides, sulfates, sulfites, thiosulfates, phosphates, halogens	2. Alcohols, glycols, amines, amides, imines, inides
3. Amides, nitrates, (except ammonium nitrate), nitrites, azides, nitric acid	3. Hydrocarbons, esters, aldehydes
4. Hydroxides, oxides, silicates, carbonates, carbon	4. Ethers, ketones, ketenes, halogenated hydrocarbons, ethylene oxide
5. Sulfides, selenides, phosphides, carbides, nitrides	5. Epoxy compounds, isocyanates
6. Chlorates, perchlorates, perchloric acid, chlorites, hypochlorites, peroxides, hydrogen peroxide	6. Peroxides, hydroperoxides, azides
7. Arsenates, cyanides, cyanales	7. Sulfides, polysulfides, sulfoxides, nitriles
8. Borates, chromates, manganates, permanganates	8. Phenols, cresols
9. Acids (except nitric)	
10. Sulfur, phosphorus, arsenic, phosphorus pentoxide	

NOTE: If you store volatile materials (ether, hydrocarbons, etc.) in a refrigerator, the refrigerator must be explosion-proof. The thermostat switch or light switch in a standard refrigerator may spark and set off the volatile fumes in a refrigerator and thus cause an explosion.

Surely this list is not complete and is intended only to cover the materials possibly found in an average school situation. This is not the only method of arranging these materials and is purely suggested.

Finn Scientific, Inc. P. O. Box 231, 917 West Wilson Street, Batavia, Illinois 60510

TABLE 3
INCOMPATIBLE CHEMICALS

Certain combinations of chemicals react violently, or are remarkably explosive, poisonous or hazardous in some other way when they interact. The following chart, although not complete, may serve as a reminder.

DO NOT CONTACT THESE CHEMICALS ...	WITH THESE CHEMICALS
Acetic Acid	Nitric acid, perchloric acid, ethylene glycol, hydroxyl compounds, peroxides, and permanganates
Acetone	Concentrated sulfuric and nitric acid mixtures
Alkali metals (K, Na, Ca),	Water (K and Na), carbon dioxide
Powdered Al and Mg	Carbon tetrachloride, and halogens
Ammonia, anhydrous	Mercury, hydrogen flouride, calcium hypochlorite
Chlorates	Ammonium salts, strong acids, powdered metals, sulfur, and finely divided organic materials
Copper	Acetylene and hydrogen peroxide
Hydrogen sulfide	Nitric acid and certain oxidizing gases
Iodine	Acetylene and ammonia
Oxygen	Oils, grease, hydrogen, flammable liquids, solids, and gases
Sulfuric acid	Chlorates, perchlorates, permanganates, and water

TABLE 4
STUDENT SAFETY CONTRACT

______________________________ ______________________________
Class Teacher

I will:

follow all instructions given by my teacher
protect eyes, face, hands, and body while conducting class and/or laboratory activities
carry out good housekeeping practices
know where to get help fast
know the location of first-aid and safety equipment (fire extinguishers, etc.) and how
to use them
conduct myself in a responsible manner at all times in a laboratory situation.

I, ______________________________, have read this contract, studied, taken, and passed my teacher's safety test. I agree to abide by the above safety regulations and to any additional printed instructions provided by my teacher and/or the District. I further agree to follow all other written and verbal instructions given in class.

______________________________ ______________________________
Signature Date

SUGGESTIONS FOR MAKING YOUR SCHOOL'S SCIENCE FACILITY SAFER

Having completed this chapter, you may feel confident that your science classroom will be relatively safe from now on. But will it? How safe is the school in general? Here are some suggestions to help improve school-wide safety.

1. Have each member of the department complete a laboratory safety questionnaire. (An example of a questionnaire may be found in the article "Safety In Your Department," The Science Teacher, September, 1986, page 45.)

2. Identify the safety hazards that exist in your department and develop or revise the laboratory safety program in your school to correct the hazards.

3. Inventory the chemicals located in your physical science storeroom(s). (A checklist for the safe storage of chemicals may be found in the February, 1981 issue of The Science Teacher, pp. 16-19.)

4. Develop and implement a training program for students.

5. Administer to students the paper-and-pencil tests on laboratory safety management which appear after this chapter.

References

American Chemical Society: Safety in Academic Chemistry Laboratories, 1985.

James, Robert K. and Finson, Kevin D. "Wanted: Lab Aides," The Science Teacher , 53(7): 28, 1986.

National Science Teachers Association: Safety in the Secondary School Classroom and Laboratory, Washington, D.C., 1986. (Handbook available from National Science Teachers Association, 1742 Connecticut Avenue, N.W., Washington, D.C. 20009. Item #PB60, $9.00 per copy.)

Reynolds, Ronald F. "Safety In Your Department," The Science Teacher 53(6): 43, 1986.

Safety Practices For Science. Austin, TX: Texas Education Agency, Science Section, Division of Curriculum Development, 1984.

Gerlovich, J., Gerard, T., et. al. School Science Safety (Secondary), Flinn Science, Inc., 1985.

LABORATORY SAFETY MANAGEMENT TEST*

Paper and Pencil Exercise

-- for the teacher --

Circle the letter associated with the word or words that **best** completes each test item.

1. An accident is (A) an unforeseen incident (B) an unforeseen mishap (C) a physical injury (D) usually someone else's fault.
2. The responsibility for safety in the laboratory rests with the (A) classroom teacher (B) classroom teacher and students (C) students (D) building principal.
3. In the event of electrical shock the first thing to do is (A) remove victim from electrical contact (B) shut off the current (C) apply artificial respiration (D) keep victim warm.
4. Ordinary safety glasses styled like prescription glasses give (A) protection against all chemical splashes (B) protection only against direct impact or splash (C) no protection (D) protection only against particle impact.
5. Labels should be used on (A) toxic chemicals only (B) flammable chemicals only (C) chemicals in their original containers only (D) all chemical containers.
6. A solvent fire should be extinguished with (A) a carbon dioxide extinguisher (B) a carbon monoxide extinguisher (C) dry sand (D) water.
7. A chemical is considered dangerous only if it is (A) flammable (B) toxic (C) flammable and toxic (D) none of the above.
8. If acid is splashed into your eyes you should (A) report immediately to the clinic (B) wash the eyes with a neutralizer (C) apply ointment to the eyes (D) wash the eyes with water for at least 15 minutes.
9. Disposal of chemical wastes produced from a laboratory experiment should be accomplished by (A) placing in the garbage can (B) dilution (C) flushing down the drain (D) none of the above.
10. On the attached diagram of this laboratory, indicate, by name and type (if applicable), the location of each safety device.**
11. List the names of three items that should be in the first-aid kit.
12. Read the following paragraph. Then, write one or more paragraphs identifying the hazards and the preventative measures that should have been taken to prevent the accident.

    Four students in a physical science class were making up a laboratory exercise on the preparation and properties of oxygen. The teacher told them to gather the materials necessary for the experiment and to follow the safety directions in the writeup. Contrary to the directions in the writeup the students mixed potassium chlorate with red phosphorus and iron III oxide and heated them with a Bunsen burner. An explosion resulted and several students were injured.

* Teacher Note 1: This test may be used as a pre- and post-test for laboratory safety.

** Teacher Note 2: You will have to construct and provide this diagram to accompany this test.

Additional cases

1. During a physical science lab a teacher stepped out of the classroom for a few minutes to obtain a reference book from the library. In his absence a serious accident occurred.
2. On a field trip a physical science teacher allowed a group of students to cross a precarious looking footbridge. The bridge collapsed causing serious injury to several students.
3. A teacher asked two students to clean the chemical storeroom, warning them of an unlabeled jar of acid on a high shelf. A scuffle caused the acid to fall and the students were seriously burned.

LABORATORY SAFETY MANAGEMENT TEST

Paper and Pencil Exercise

-- *for the student* --

Circle the letter associated with the word or words that **best** completes each test item.

1. An accident is (A) an unforeseen incident (B) an unforeseen mishap (C) a physical injury (D) usually someone else's fault.

2. The responsibility for safety in the laboratory rests with the (A) classroom teacher (B) classroom teacher and students (C) students (D) building principal.

3. In the event of electrical shock the first thing to do is (A) remove victim from electrical contact (B) shut off the current (C) apply artificial respiration (D) keep victim warm.

4. Ordinary safety glasses styled like prescription glasses give (A) protection against all chemical splashes (B) protection only against direct impact or splash (C) no protection (D) protection only against particle impact.

5. Labels should be used on (A) toxic chemicals only (B) flammable chemicals only (C) chemicals in their original containers only (D) all chemical containers.

6. A solvent fire should be extinguished with a(n) (A) a carbon dioxide extinguisher (B) a carbon monoxide extinguisher (C) dry sand (D) water.

7. A chemical is considered dangerous only if it is (A) flammable (B) toxic (C) flammable and toxic (D) none of the above.

8. If acid is splashed into your eyes you should (A) report immediately to the clinic (B) wash the eyes with a neutralizer (C) apply ointment to the eyes (D) wash the eyes with water for at least 15 minutes.

9. Disposal of chemical wastes produced from a laboratory experiment should be accomplished by (A) placing in the garbage can (B) dilution (C) flushing down the drain (D) none of the above.

10. On the attached diagram of this laboratory, indicate, by name and type (if applicable), the location of each safety device.

11. List the names of three items that should be in the first-aid kit.

12. Read the following paragraph. Then, write one or more paragraphs identifying the hazards and the preventative measures that should have been taken to prevent the accident.

> Four students in a physical science class were making up a laboratory exercise on the preparation and properties of oxygen. The teacher told them to gather the materials necessary for the experiment and to follow the safety directions in the writeup. Contrary to the directions in the writeup the students mixed potassium chlorate with red phosphorus and iron III oxide and heated them with a Bunsen burner. An explosion resulted and several students were injured.

Electricity

Background Information

9

Electricity is one of the fundamental properties of matter, which all matter possesses. It is composed of two types of charge, and these types have been labeled **positive** or **negative.** The operational definition of positive and negative charge involves rubbing silk and fur against glass and rubber. For the purposes of the physical science course, it may be assumed that charge is carried by protons and electrons, the protons being positively charged and the electrons being negatively charged.

There is no metric unit of charge. The SI unit is the **Coulomb** (abbreviated C). One Coulomb is a tremendous amount of charge, and the effects of much less than one coulomb observable in the classroom (e.g., the charge on a Van der Graaff generator) are microcoulombs or less. The charge on the electron is 1.6×10^{-19} C.

Charges exert forces on each other through what is called the **electric field.** These electric forces are the forces that ultimately hold matter together. Electric fields store energy in the field itself, and natural processes always tend to reduce this energy if possible. Atoms are electrically neutral because the positive and negative charges arrange themselves to produce zero field outside the atom. A charged atom (ion) is in an elevated energy state and will seek a charge of opposite sign so as to be electrically neutral.

Some atoms and molecules have charges arranged to give a weak electric field external to the atom. The word **polar** is used to describe these atoms and molecules. Although these atoms and molecules are electrically neutral, they still have a weak external electric field. For polar atoms and molecules, the rules of quantum physics dictate electronic states that have symmetries such that the field outside the atom or molecule is not zero.

The word "electricity" is most often used with reference to charges flowing in a metallic conductor. This charge motion is rather complex because the rules that govern the motion are dictated by quantum mechanics. The rules of quantum mechanics are different from those we live by in our macroscopic world. Consequently we have little intuitive framework to deal with them. For the average ninth grader, the quantum rules will be too sophisticated to understand, so a simple model is used for charge conduction in solids.

The usual pattern for discussing effects of electricity is to start with static electricity and move on from there to current flow. This is potentially misleading from a teaching point of view for two reasons:

1) Static charges are always the result of electrons moving onto or away from an object which was originally electrically neutral. On the other hand, **electric currents** are the **result of the motion of either positive or negative charges.** In solids, the currents may be either positive charges or negative charges. In some solid conductors, electric currents are the result of simultaneous motion of both positive and negative charges. This is important information for a science teacher to know in order to accurately instruct students on the topic of electricity.

2) It is possible for static electricity to be misinterpreted as being different from current electricity--they both involve the same charges. We will discuss static charges first because it is easier to describe the terminology with static systems. However, everything discussed in terms of forces and energies applies equally well to static or moving charges.

Conservation of Charge

Static charges are the result of an excess or deficiency of electrons. Objects with these electron states are said to be "charged". The charge may be either positive or negative, depending on the charging process. However, one of the most fundamental rules of physics is that charge is conserved, meaning that when one object is charged positive, some other object is charged negative. The total amount of electric charge in the universe is a constant, and no experiment can create or annihilate electric charge. When a bit of negative charge is isolated, somewhere there is an exactly equal unit of positive charge.

Perhaps you have heard of the material called "anti-matter". The first "anti-" particle found was the positively charged electron. Since electrons as we know them are normally negative, the positive electron was indeed strange. In fact, if a positive and a negative electron come into contact with each other, they will annihilate each other and convert completely into energy. Thus, they will no longer exist in their original form.

Antimatter can exist because of the relativistic condition that $E = mc^2$. High energy gamma rays (which are electromagnetic waves) can, in the presence of a heavy nucleus such as lead, transform into **two** particles, an electron and a positively charged particle having the same mass and charge magnitude as the electron. Two particles must be created (one positive and the other negative) in order to conserve charge, and the heavy nucleus is necessary to conserve momentum. There is also a threshold energy for the process because of conservation of energy. The positive electron is called a **positron.**

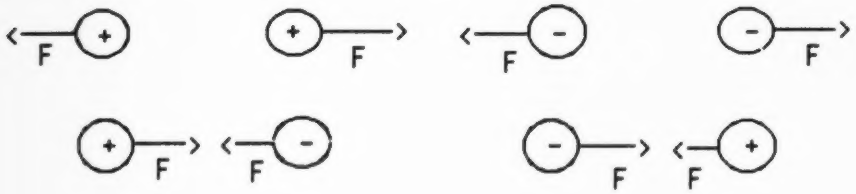
Coulomb's Law

Isolated charges exert forces on other charges according to **Coulomb's Law.** The interaction force between two charges is attractive if the charges are opposite and repulsive if the charges are alike. The magnitude of the force is given by the formula

$$F = \frac{kq_1q_2}{r^2}$$

where q_1 and q_2 are charges small enough to be considered as "point" charges, r is the separation distance between these charges and k is a constant depending on the medium in which the charges are imbedded and the units used for charge and distance. In the SI system, k has the value $9 \times 10^9\ N\ m^2/C^2$ in a vacuum.

The four possible charge configurations are illustrated below:



All electric forces (F) result from Coulomb's Law.

Electric Field

Electric charges move to produce electric currents and static charges because of forces which act on those charges. The motion is consistent with Newton's law F = ma. The force in Newton's law is the resultant force, which in general is the vector sum of many different forces. It is extremely convenient to use the concept of a **field** when studying electricity, because most of the time the charges are not point charges but rather are distributed over some surface. A given charged object will be accelerated by all of the forces acting on it from all of these distributed charges. Every electric force is consistent with Coulomb's law, but when many forces act it may be impossible to identify any one of the individual Coulomb forces.

The electric field is defined as the electric force per unit charge that acts on any charged object. The field is not a force. The field is a property of space. No force acts until a charge is present.

The operational definition for a field is to take a "test charge" q_0 and place it in a region of space. The electric force F acting on the charge, divided by the charge q_0, is the electric field E.

$$E = \frac{F}{q_0}$$

(This is a vector equality.)

For an isolated point charge q, the field at any point in space a distance r from the charge is

$$E = \frac{F}{q_0} = \frac{k q q_0 / r^2}{q_0} = k q / r^2$$

When any charge Q is placed at r, the force will be EQ, which is of course Coulomb's law. If many changes are around, the resultant field is the superposition of the fields of all the individual charges.

Electric Currents

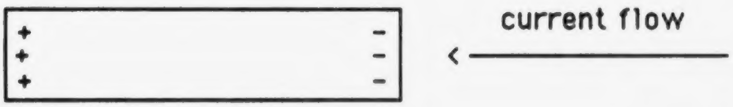
Electric current is, by definition, charge in motion. In liquids and gases, currents result from motion of both positive and negative ions as well as electrons. Charge motion in solids is extremely complex, governed by the rules of quantum mechanics. In fact, if it were not for the quantum rules, all solids would conduct and there would be no insulators.

The model of conduction which describes electric current as moving electrons is a nice and simple model. Unfortunately, it is also only half true. In free space the electron is much less massive than a proton, so is more easily accelerated to high velocities. The interior of a material is not free space, and, although it may be intuitive to think that the electron will still be more easily moved than a positive ion, the true picture is just not that simple.

A number of materials conduct electricity by the motion of moving positive charges. These charges are not the ions but are rather the absence of an electron in what would normally be an occupied electronic energy state. Remember ordinarily matter is neutral, and if an electron is removed the matter is charged positive. Metals such as tungsten, aluminum, zinc and cadmium as well as materials called semi-conductors all conduct electricity by the motion of moving charged empty electron states. These empty states are called **holes** and behave just like traditional particles while inside the solid. They are deflected in a magnetic field. They even have mass which can be detected inside the material.

This is a confusing state of affairs and is not easy to conceptualize. Unfortunately, it is the way the electrical nature of matter is presently believed to exist. Most likely the original designation of positive charge was made because it was thought that these charges were the more easily moved. It was impossible at the time to determine which charge jumped an arc from a positively to a negatively charged object. Benjamin Franklin is said to have called the charge that he thought moved more easily "positive" and his guess turned out to be inaccurate. In any event, as electrical engineering developed, all of the laws treated current as moving positive charge. Any student who goes into advanced study involving electronics who has learned electric current as electron flow will ultimately have to relearn a new definition for current.

It is instructive to look at how really difficult it is to tell whether the currents are the result of moving positive or negative charge. The transport process is essentially instantaneous and without sophisticated equipment we cannot tell what is moving, but only the end result of charge separation. Currents flowing through a material will result in charges accumulating at the ends, as represented below:



This accumulation can be brought about equally well by any of three mechanisms:

1) The positive charges remain fixed and the negative charges move to the right. An unbalanced positive charge is left behind at the left.

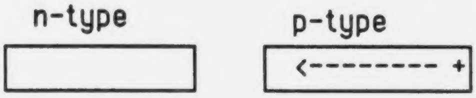
2) The negative charges remain fixed and the positive charges move to the left. An unbalanced negative charge is left behind at the right.
3) Positive charges move to the left and negative charges move to the right.

Solid materials condut electricity in different ways. If the predominate charge carriers are negative charges, the conductor is said to be an **n-type**. If the predominate charge carriers are positive charges, the conductor is said to be a **p-type**. If both move, the conduction is called **intrinsic**. By convention, the direction of the electric current is taken as being in the direction of moving positive charges and opposite to moving negative charges (electrons).

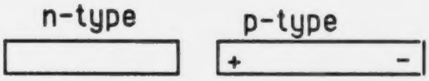
Consider charge motion in an n-type and a p-type material adjacent to each other.

n-type
p-type

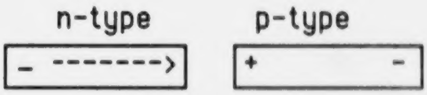
Suppose a positive charge leaves the right side of the p-type material and migrates to the left.



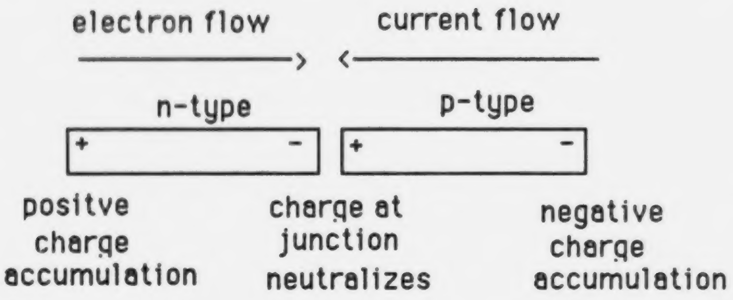
The result of this motion will be a positive charge at the left and negative charge at the right.



Now consider the result of a negative charge leaving the left of the n-type material and moving to the right. The result will be positive charge on the left and negative charge on the right.



If the two materials are joined, the charges at the extreme ends are not affected. In the middle, the charges neutralize and the end result is a rod charged positive on the left and negative on the right. The device that actually works this way is called a p-n junction, used for rectifying alternating current.


electron flow
current flow
n-type
p-type
+
-
+
-
positve charge accumulation
charge at junction neutralizes
negative charge accumulation

Basically, it makes no real difference which charge is used as the defining carrier for electric current. However, only one definition is allowed and current may not simultaneously be in the direction of motion for both types of charge carriers. If electron flow is used as the defining flow for current, the students who go on for further study will be at a disadvantage.

Electric Potential (Voltage)

Voltage is often described as the "push" on charges that cause them to move. Texts even talk about the "electromotive force". This is an extremely unfortunate descriptor because it conceptualizes voltage as a force. Voltage is energy per unit charge (joules per coulomb). In the static case the energy is potential energy, so the word potential is a derivative of this nomenclature.

Potential energy results from forces acting through distances, but energy is not a force. Gravitational potential energy is mgh. Weight is mg. Since mgh is not mg, electric energy is not electric force.

Electric potential is related to the electric field. Potential energy per charge is force per charge times distance moved. Force per charge is field, so the potential difference ΔV between two points in an electric field is the product of the electric field E and the distance moved D.

$$\Delta V = E\,D.$$

The unit of electric potential is the Volt (V), and one volt is one joule per coulomb. The popular unit for energy when discussing atoms is the electron-volt (eV), which is the energy involved in moving one electronic charge through a potential of one volt. Since the charge on the electron is 1.6×10^{-19} C, the electron volt is 1.6×10^{-19} J.

$$1\ \text{eV} = 1.6 \times 10^{-19}\ \text{J}$$

One popular energy source is the battery. Batteries come in all sizes and voltages. All batteries of the same voltage deliver the same energy per coulomb. The 12 volt transistor battery cannot start your car because the total energy available is not adequate. However, for the coulombs it does supply, each has the same energy as the coulombs from a larger battery.

Electric Circuits

The word "circuits" is used to describe the study of charges moving through materials. The physical science course is concerned only with the most simple circuits, called series and parallel, but even in these simple circuits there are effects that directly influence what students will find when they participate in laboratory exercises. Any source of electric energy has an inherent resistance of its own that may not always be ignored.

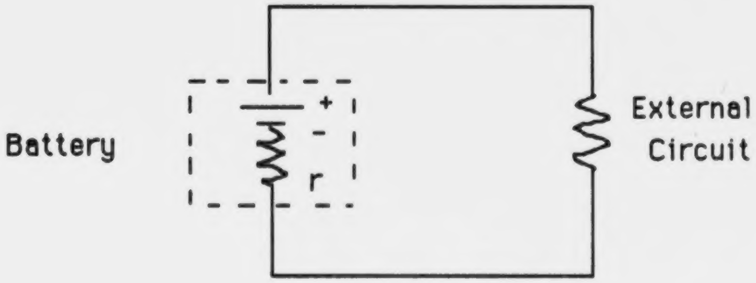
The parts of an electric circuit are a power source and something that converts electric energy to some other form of energy. For our purposes, we will call the source of power a "battery" and the circuit elements "resistors". Often small light bulbs are used in demonstration circuits, and in these devices electric energy is converted to light. Another circuit might have a motor. Everything will be lumped together as "resistors".

When charges are free to move, they gain energy from the field and convert this into kinetic energy. When the accelerated charges interact with the lattice of a solid, the kinetic energy is converted to internal energy of the material. This internal gain produces a temperature increase. The source of the energy which produces the original field and accelerates the charges is the battery.

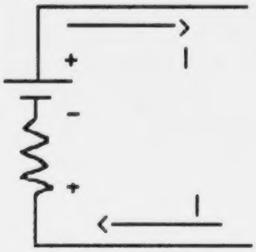
Batteries are not perfect devices. Being made up of conducting materials, they have an inherent resistance of their own. The result of this "internal resistance" is a voltage drop inside the battery which reduces the amount of voltage the battery can deliver to a given circuit. Although the textbook treatments give battery voltages as fixed and independent of current this is not what actually happens.

The value of the internal resistance varies from battery to battery, depending on the size, age and history of the battery. Typically, a "good" dry cell will have internal resistance of about one ohm. "Bad" cells are bad by the definition that they have internal resistance of tens to thousands of ohms. Somewhere in between are the "weak" batteries.

Internal resistance is represented schematically as a resistor r in series with the voltage source Vo.



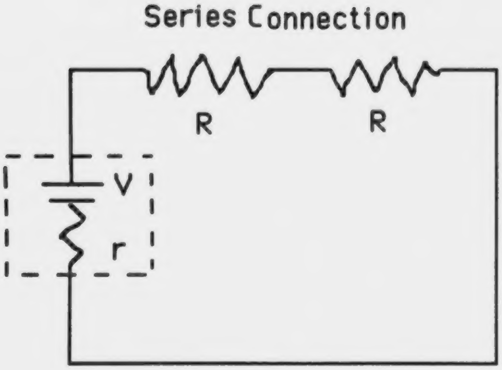
When the circuit is completed and a current I flows (being usually defined as moving positive charge coming from the positive terminal of the battery) the polarization of the internal resistor is opposite to that of the battery.

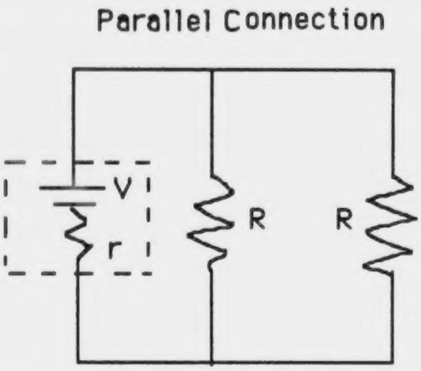


The voltage at the terminals (called the Terminal Potential Difference or TPD) is (Vo - Ir). Under load the voltage across the battery decreases from the value when no current is flowing.

The internal resistance is a hidden but real part of any electric circuit. In the classroom, this resistance can lead to results that are completely different from the textbook explanations.

For example, a comparison between the series and parallel connection is a commonly suggested experiment. The drawings invariably omit the internal resistance. The correct representation is given below.


Series Connection


Parallel Connection

A text might use light bulbs for the resistors and ask the question "Which connection gives the brighter bulbs?" The given answer is "The series connection." The correct answer is "It depends on the value of the internal resistance (r) of the battery." It is perfectly possible for the series bulbs to be brighter than the parallel bulbs. In fact, for a two bulb connection, if r (internal resistance) is equal to R (external resistance) the bulbs in series are exactly the same brightness as the bulbs in parallel. If r is greater than R, the series bulbs are brighter. Only when r is less than R does the observation agree with the textbook.

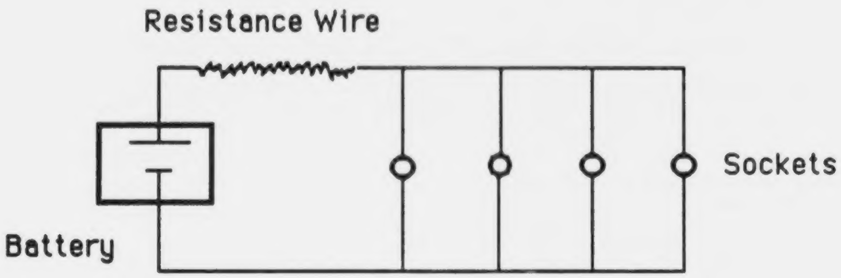
Typically the resistance of a hot five watt six volt flashlight bulb is about 5 ohms. This bulb will draw about one ampere from a fresh battery. A good six volt cell might have resistance of 1/2 to 1 ohm, so the battery will deliver about 5 1/2 volts to the bulb. (This means that the actual operating voltage (the TPD) of the operating battery is 5 1/2 volts.)

However, batteries do not stay fresh long in a classroom, and if the battery has been abused (for example shorted so as to watch the sparks), the resistance might be 9 to 10 ohms. A battery with this internal resistance will deliver to the same bulb only about 1/2 ampere and the TPD will be only about two volts. Instead of five watts, the bulb will radiate only about one watt. The bulb doesn't glow as bright, and we say the battery is "weak".

Brownout Demonstration

Brownout is the word given to a lowering of the voltage from a power source because of too heavy current demand. The word comes from the reddening of lights when operated at a voltage less than that for which they are rated.

The internal resistance is a resistance in series with the voltage source, so any resistance in series with the battery has the same effect. If a lead wire is made of resistance wire so that there is a voltage drop in the wire, a good battery behaves just like a battery with large internal resistance. The circuit below represents a battery connected to four bulb sockets in parallel connection.



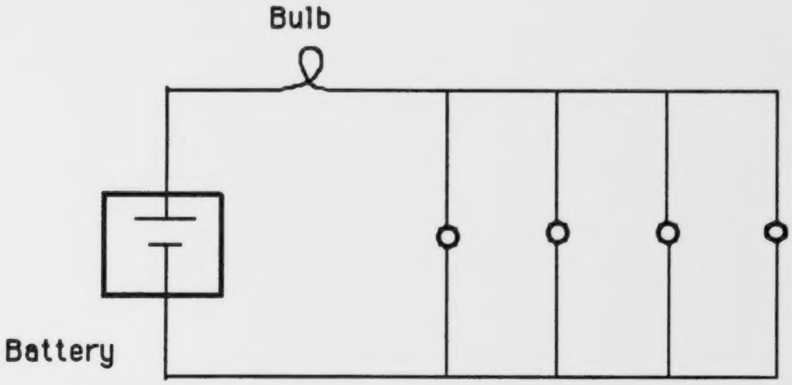
For the resistance lead, use a sufficient length of resistance wire to have three to five ohms resistance. Typically, resistance wire will have a resistance of 1.5 to 2 ohms per foot, so a three foot length will have about the right resistance. The extra wire can be made less obvious by curling it into a coil by wrapping it around a pencil and then removing the pencil.

Screw a bulb into any of the sockets. It should burn brightly.

To demonstrate brownout, screw a second bulb into a socket. The first bulb will dim. Screw the third bulb into a socket. The dimming of the first two will be significant. When the fourth bulb is screwed in, the glow should be very weak. The filaments will be a dull red. Unscrew the bulbs one at a time, noticing how the remaining bulbs brighten as a bulb is removed.

Discussion

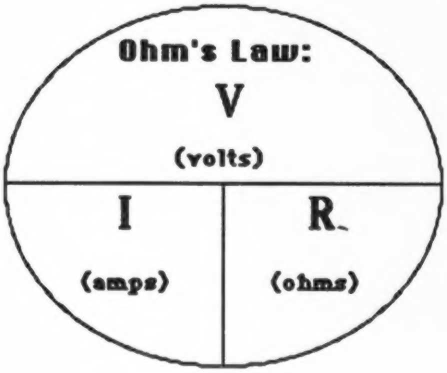
The dimming of the bulbs occurs because the additional current required to light additional parallel bulbs causes a greater voltage drop in the internal resistance. To show this, make a similar circuit as before, except replace the hidden resistance in the resistance wire with a light bulb.



When the first bulb is screwed in, the series and new bulb will light, each burning equally bright. As subsequent bulbs are added, the series bulb brightens because all of the current through all parallel bulbs must go through it. However, because the voltage drop across the series bulb increases there is a reduced voltage across the parallel connection. When all four parallel bulbs are screwed in, the series bulb will be very bright while the parallel bulbs are dim. The brightness of the series bulb is a measure of the current being delivered by the battery and the voltage lost in the circuitry leading to the parallel connection.

SERIES CIRCUITS
Paper and Pencil Exercise
--for the teacher--

Solve for each missing value by using Ohm's Law and the rules for series circuits.



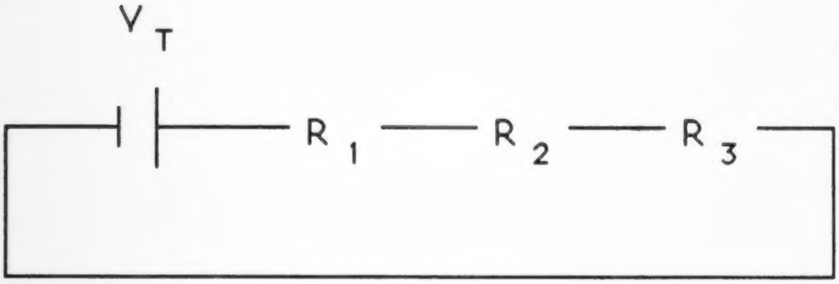
Experienced science teachers have found that this pictorial representation is helpful to students when they attempt to solve Ohm's Law problems

Rules:

$V_T = V_1 + V_2 + V_3 + \ldots\ldots + V_n$

$I_T = I_1 = I_2 = I_3 = I_n$

$R_T = R_1 + R_2 + R_3 + \ldots\ldots + R_n$



Note that the values on the teacher's version of this exercise are all entered which is not the case on the student's version.

V_T 8 volts	V_1 6 volts	V_2 2 volts
I_T 0.2 amps	I_1 0.2 amps	I_2 0.2 amps
R_T 40 ohms	R_1 30 ohms	R_2 10 ohms

V_T 6 volts	V_1 4 volts	V_2 2 volts
I_T 0.5 amps	I_1 0.5 amps	I_2 0.5 amps
R_T 12 ohms	R_1 8 ohms	R_2 4 ohms

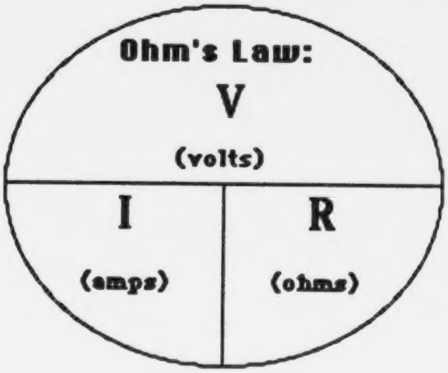
V_T 26 volts	V_1 6 volts	V_2 12 volts	V_3 8 volts
I_T 4 amps	I_1 4 amps	I_2 4 amps	I_3 4 amps
R_T 6.5 ohms	R_1 1.5 ohms	R_2 3 ohms	R_3 2 ohms

SERIES CIRCUITS

Paper and Pencil Exercise

--for the student--

Solve for each missing value by using Ohm's Law and the rules for series circuits.

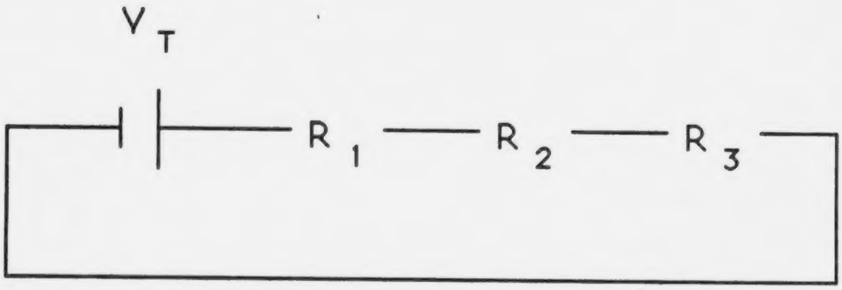

Ohm's Law:
V
(volts)
I
(amps)
R
(ohms)

Rules:

$V_T = V_1 + V_2 + V_3 + ... + V_n$

$I_T = I_1 = I_2 = I_3 = I_n$

$R_T = R_1 + R_2 + R_3 + ... + R_n$



V_T 8 volts	V_1	V_2
I_T	I_1	I_2
R_T	R_1 30 ohms	R_2 10 ohms

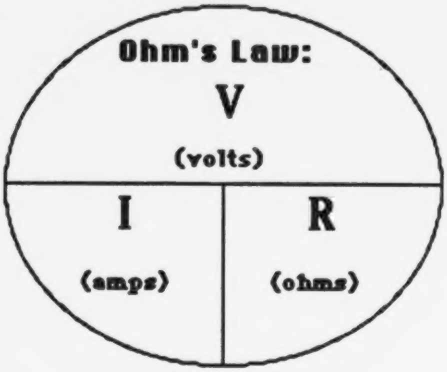
V_T	V_1 4 volts	V_2
I_T	I_1	I_2
R_T 12 ohms	R_1	R_2 4 ohms

V_T	V_1	V_2	V_3
I_T 4 amps	I_1	I_2	I_3
R_T	R_1 1.5 ohms	R_2 3 ohms	R_3 2 ohms

PARALLEL CIRCUITS

Paper and Pencil Exercise
--for the teacher--

Solve for each missing value by using Ohm's Law and the rules for parallel circuits.

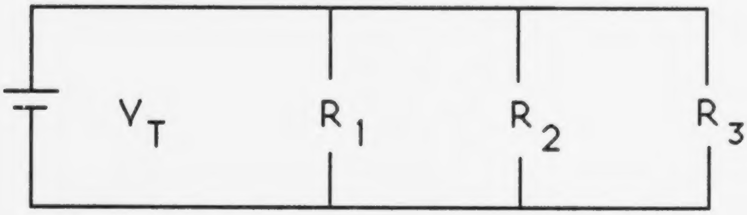


Experienced science teachers have found that this pictorial representation is helpful to students when they attempt to solve Ohm's Law problems.

Rules: $V_T = V_1 = V_2 = V_3 = \dots\dots = V_n$

$I_T = I_1 + I_2 + I_3 + \dots\dots + I_n$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots\dots + \frac{1}{R_n}$$



Note that the values on the teachers version of this exercise are all entered but this is not the case on the student's version.

V_T 6 volts	V_1 6 volts	V_2 6 volts
I_T 2 amps	I_1 1.5 amps	I_2 0.5 amps
R_T 3 ohms	R_1 4 ohms	R_2 12 ohms

V_T 9 volts	V_1 9 volts	V_2 9 volts
I_T 4.5 amps	I_1 1.5 amps	I_2 3 amps
R_T 2 ohms	R_1 6 ohms	R_2 3 ohms

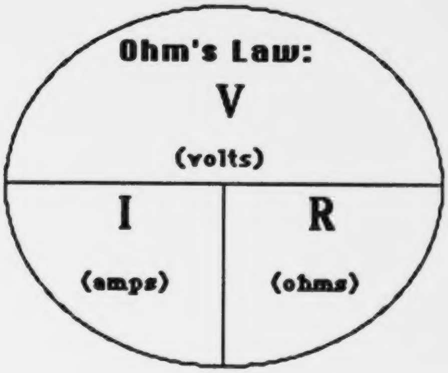
V_T 5 volts	V_1 5 volts	V_2 5 volts	V_3 5 volts
I_T 4 amps	I_1 2.5 amps	I_2 0.5 amps	I_3 1 amps
R_T 1.25 ohms	R_1 2 ohms	R_2 10 ohms	R_3 5 ohms

PARALLEL CIRCUITS

Paper and Pencil Exercise

--for the student--

Solve for each missing value by using Ohm's Law and the rules for parallel circuits.

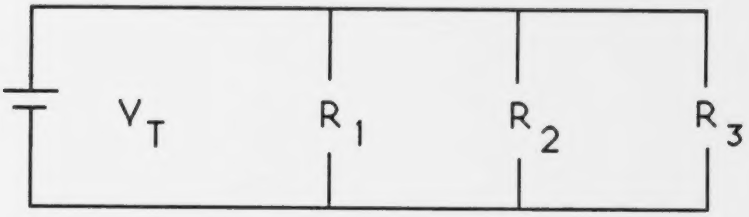

Ohm's Law:
V
(volts)
I
(amps)
R
(ohms)

Rules:

$V_T = V_1 = V_2 = V_3 = \ldots\ldots = V_n$

$I_T = I_1 + I_2 + I_3 + \ldots\ldots + I_n$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots + \frac{1}{R_n}$$



V_T	V_1	V_2
I_T 2 amps	I_1	I_2
R_T	R_1 4 ohms	R_2 12 ohms

V_T 9 volts	V_1	V_2
I_T	I_1	I_2
R_T	R_1 6 ohms	R_2 3 ohms

V_T	V_1	V_2	V_3
I_T 4 amps	I_1	I_2	I_3
R_T	R_1 2 ohms	R_2 10 ohms	R_3 5 ohms

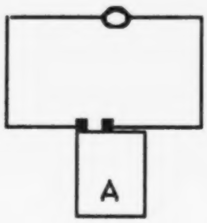
THINK TIME

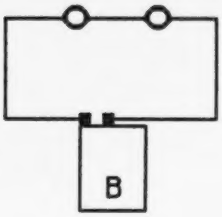
Paper and Pencil Exercise

--for the teacher--

LIGHT, LIGHT, AND MORE LIGHT

A lamp is connected to a battery. A second lamp is connected in series to the same battery. When two lamps are connected, the battery puts out...





A. *less current*
B. more current
C. less voltage
D. the same current

Which arrangement produces the most light?

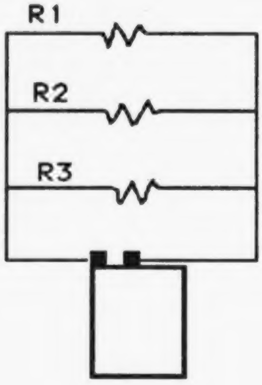
A. *A*
B. B
C. both are the same

Justify or explain your answers.

Answer -- Two identical bulbs connected in series have twice the resistance of one bulb. The voltage of the battery is the same. Voltage is equal to the current times the resistance, therefore, as resistance increases current decreases. The total power to the lights is a product of the voltage and current so a decrease in current results in a decrease in power.

PARALLEL, THAT'S THE WORD

In the parallel circuit below, the voltage drop across each resistor is..

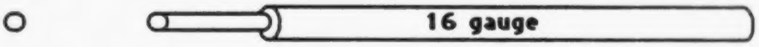


A. divided equally among the three resistors.
B. dependent on the overall resistance.
C. *the same in all three resistors.*

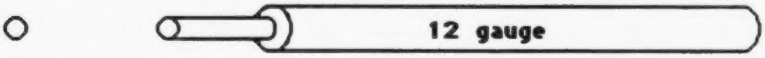
THROUGH THICK OR THIN

The diameter of electrical wire is indicated by a **gauge** number. The smaller the number, the greater the diameter. What gauge of wire would be best for carrying electricity to major appliances such as washing machines and clothes driers. Justify your answer.

A.



B.



C.

Answer -- The 10 gauge wire is used in 120 volt circuits for major appliances. The 12 gauge is used in standard 120 volt circuits for lighting and small appliance receptacles. The 16 guage is usually reserved for low voltages and is commonly referred to as bell wire. As the diameter of the wire decreases, its resistance increases. Thus, 16 gauge wire offers more resistance than 10 gauge wire. Since large appliances draw more current it is best to use thicker wire. The thicker wire offers less resistance and therefore produces less heat from friction. Using too thin a diameter wire can be a fire hazard.

DANGER

Is it possible to have a situation in which there exists a lot of voltage without having a lot of current at the same time? Explain.

Answer -- Yes. The Van de Graaff generator is a good example. Energy is required to separate positive and negative charges. The separated charges have electric potential energy. The amount of electric potential energy per charge is the voltage. On a fully charged 12 volt battery, for example, the opposite charges on the battery terminals have an energy of separation of 12 units of energy per unit of charge, or 12 volts. 12 volts = 12 joules/coulomb. If the dome of a Van de Graaff generator is charged to 100,000 volts, then each coulomb of charge on the dome has a potential energy of 100,000 joules, but the generator does not have many coulombs.

HIGH AMPERAGE, LOW VOLTAGE?

The unit of electric current is the ampere. Can there be a situation where there is a lot of amperage without also having a lot of voltage at the same time?

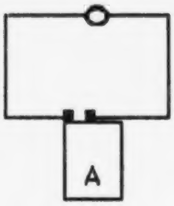
The answer is yes. The amount of current in a simple circuit depends on voltage and on the resistance in the circuit. If the resistance is low, a small voltage can result in a large current flow. A good example would be a situation in which **superconductors** are used. In cryogenic studies, it has been found that substances cooled to nearly absolute zero have extremely low resistance--possibly no resistance at all. This means that you can get very large current with very little investment of energy.

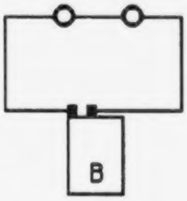
THINK TIME

Paper and Pencil Exercise
--for the student--

LIGHT, LIGHT, AND MORE LIGHT

A lamp is connected to a battery. A second lamp is connected in series to the same battery. When two lamps are connected in series as shown, the battery puts out..





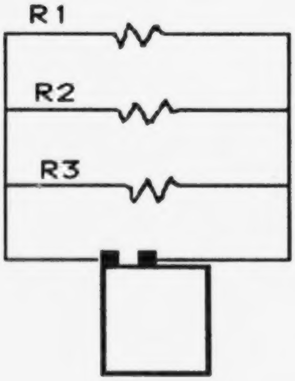
A. less current
B. more current
C. less voltage
D. the same current

Which arrangement puts out the most light?
A. A
B. B
C. both are the same

Justify or explain your answers.

PARALLEL, THAT'S THE WORD

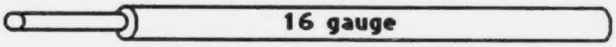
In the parallel circuit below, the voltage drop across each resistor is..

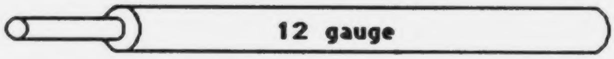


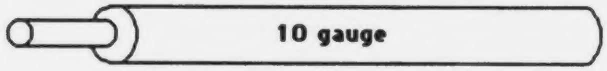
A. divided equally among the three resistors.
B. dependent on the overall resistance.
C. the same in all three resistors.

THROUGH THICK OR THIN

The diameter of electrical wire is indicated by a **gauge** number. The smaller the number, the greater the diameter. What gauge of wire would be best for carrying electricity to major appliances such as washing machines and clothes driers.

A. ○ 

B. ○ 

C. ○ 

Justify your choice. ____

____

____

____

DANGER! HIGH VOLTAGE

It is possible to have a situation in which there exists a lot of voltage without having a lot of current at the same time? Explain.

____

____

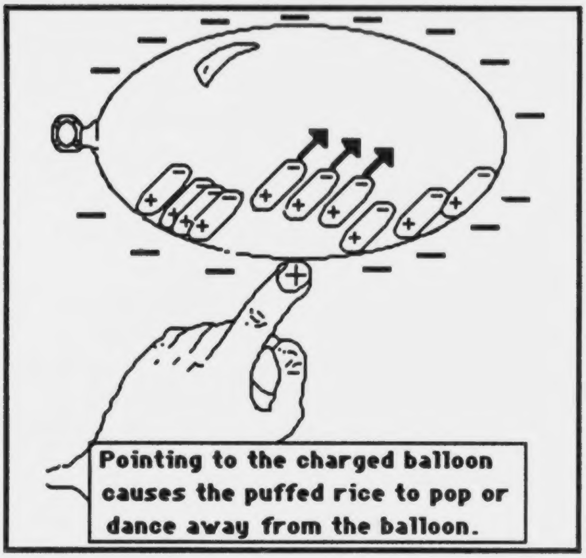
____

____

____

____

DANCING RICE
Demonstration



Pointing to the charged balloon causes the puffed rice to pop or dance away from the balloon.

PURPOSE

The purpose of this activity is to demonstrate the behavior of static electric charges. The student will charge a balloon containing puffed rice and will explain why the uncharged pieces of puffed rice dance inside the balloon when he or she points to them.

MATERIALS

Rubber balloons (long balloons work best)
Puffed rice cereal (not sugar coated)
Wool cloth

PROCEDURES

A. Put about 10 pieces of plain puffed rice in a rubber balloon.
B. Blow up the balloon and secure the open end with a knot.
C. Rub the balloon briskly with a piece of wool cloth or through your clean dry hair.
D. Using your free hand, bring your pointing finger toward the pieces of puffed rice.

The rice pieces pointed to will be repelled.

E. Hold the balloon upright and observe the pieces of rice.

The pieces of rice are being attracted by the charged balloon.

What charge does the balloon have? .. the rice pieces?

Answer -- The balloon is rubber and was rubbed with hair or wool so it becomes negatively charged. The rice pieces were not rubbed so they remain relatively neutral.

Why are the pieces of rice attracted to the charged balloon?

Answer -- Through induction the negative particles in the puffed rice are repelled away from the side of the rice nearest the negatively charged balloon thus leaving that point on the puffed rice with a positive charge. This positive charge is attracted by the negative charge on the balloon.

What happens to the charged particles in your finger as you bring it near but not touching the negatively charged balloon?

Answer -- The negative particles nearest the negatively charged balloon are repelled thus leaving the point of your finger with a positive charge.

Why do the pieces of rice dance or pop away from the charged balloon when you point to them?

Answer -- Remember the point on the rice nearest the balloon is positive and your finger is also positive. The positive finger tip repels the positive point on the pieces of rice.

THE ELECTROSCOPE

Demonstration

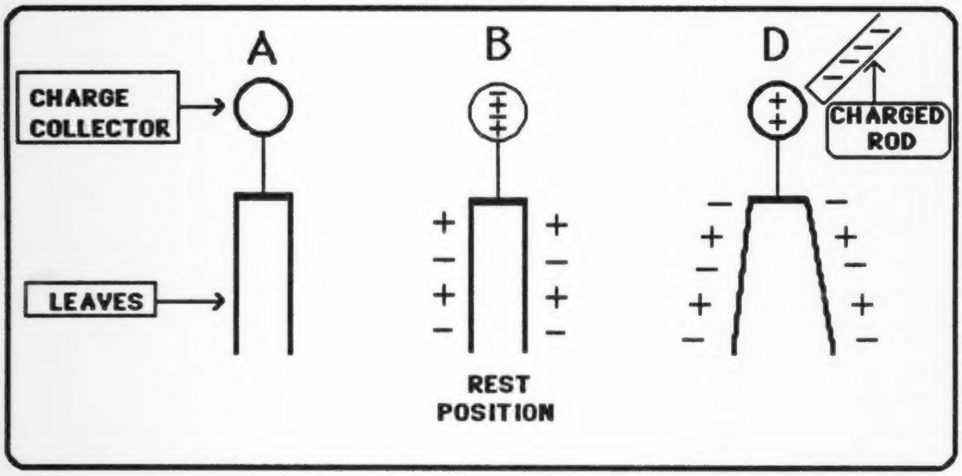
PURPOSE

The purpose of this demonstration is to explain how an electroscope works and to demonstrate the behavior of charges.

MATERIALS

Electroscope
Hard rubber rod or comb
Wool cloth or your clean dry hair

PROCEDURES



PROCEDURE

A. Identify the parts of the eletroscope (charge collector and leaves). Identify the rest position or neutral position (leaves hanging straight down).

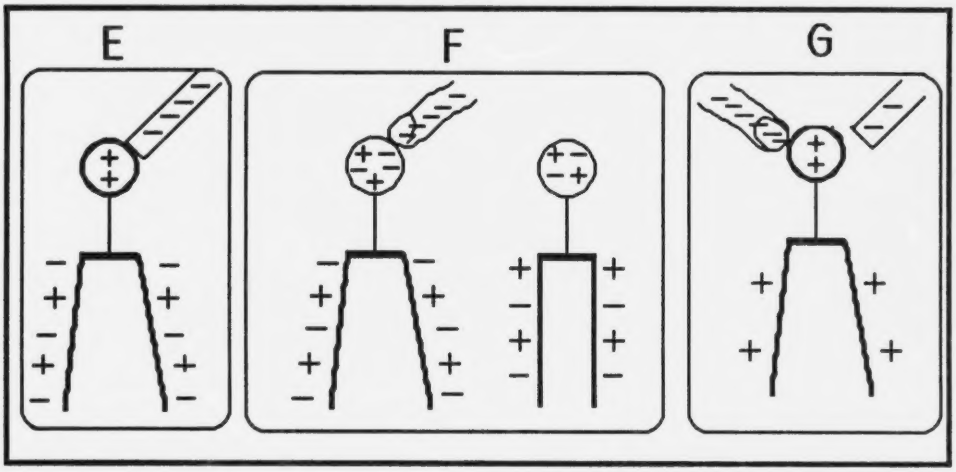
B. Explain to students that a neutral electroscope has an equal number of positively charged particles and negatively charged particles distributed evenly through the entire electroscope.

C. Charge a hard rubber rod or plastic comb by rubbing it briskly through your clean dry hair or with a piece of wool.

D. Bring the charged rod near but not touching the charge collector. Ask students to describe what happens and to explain their observation.

Answer -- The leaves spread apart. The negatively charged rod repelled the negatively charged particles in the charge collector to the leaves. Since both leaves became negatively charged, they repelled each other and moved apart.

PROCEDURES



E. Touch the charged rod to the charge collector then move it away. Ask students to describe and explain what happens.

Answer -- The leaves remain apart. The negatively charged rod again repels the negatively charged particles in the charge collector down to the leaves. This leaves the charge collector with a positive charge. When the negatively charged rod touches the positively charged collector, negatively charged particles are transferred to the charge collector. This leaves the entire electroscope with an excess of negatively charged particles. Like charges repel.

F. Touch the charged electroscope with your finger. Ask students to describe and explain what happens.

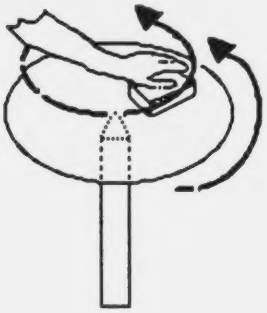
Answer -- The leaves of the electroscope return to rest position. The excess negative charges in the electroscope move from the electroscope to your finger. Your finger acts as an electrical ground.

G. Recharge your rubber rod. Bring the charged rod near but not touching the charge collector. Touch the charge collector with your finger while still holding the charged rod near by. Move both your finger and the charged rubber rod away from the collector at the same time . Ask students to describe and explain what happens.

Answer -- The leaves move apart when the rod is brought near the charge collector. They return to rest when you touch the collector however, they move apart when both the rod and finger are moved away at the same time. As long as the charged rod and your finger are present, the excess negatively charged particles move onto your finger thus giving the charge collector a positive charge. When your finger and the rod are removed, the entire electroscope is left with an excess of positively charged particles.

WILL A MAGNET ATTRACT ALUMINUM?

Demonstration



PURPOSE

The purpose of this activity is to demonstrate the relationship between magnetism and electricity. The student is presented with a discrepant event to explain.

MATERIALS

Aluminum disc (cut from a sheet of aluminum with tin snips)
Pivot point stand
Strong bar or horseshoe magnet. The magnet must be very powerful for this demonstration to work.

PROCEDURES

1. Balance the aluminum disc on the pivot point stand so that it's free to rotate about its center.

2. Hold the magnet aprroximately one to two inches above the aluminum disc and rotate it over the disc. Begin your circular motion slowly and the disc should rotate in the same direction as the magnet. When you speed up the rotation of the magnet above the disc, the disc should rotate faster. Ask the students:

What happens when the magnet is rotated above the aluminum disc?

Answer -- The aluminum disc begins to spin and follow the rotation of the magnet.

Does the aluminum have magnetic properties?

Answer -- No.

Why is there an attraction between the magnet and the aluminum disc, if the aluminum is not attracted by a magnetic field?

Answer -- We create an electric current in the aluminum disc when we rotate the magnet over it. There is a law in physics which states that a changing magnetic field produces a current in a nearby conductor. Thus, when we rotate the magnet we produce a changing magnetic field, which in turn induces a voltage and current in the aluminum. Aluminum is a conductor of electricity and is used in the manufacture of electrical conductors.

Moving a magnetic field can affect the disc and cause it to rotate. This is explained by another law of physics, which states that a magnetic field exerts a force on an electric current.

HOW DO SERIES AND PARALLEL CIRCUITS WORK?

Laboratory Exercise
--for the teacher--

PURPOSE

The purpose of this exercise is to demonstrate the difference between series and parallel circuits.

MATERIALS

6 volt dry cell or DC power supply
3 light bulbs with sockets
Switches
Insulated copper wire for connections

PRELABORATORY DISCUSSION

In this lab students will be asked to wire bulbs in series and in parallel. It might be necessary to review circuits beforehand. Remind students to be careful with their connections. Students have a tendency to forget that current cannot flow through the insulation nor can it flow through conductors that are not in contact at the point of connection. Questions might include:

What is a circuit?

Answer -- A circuit is a path through which electric charges can flow. All simple circuits have three features in common:

a source,
a load that converts electric energy, and
a conductor to provide the complete or closed path.

What is a series circuit?

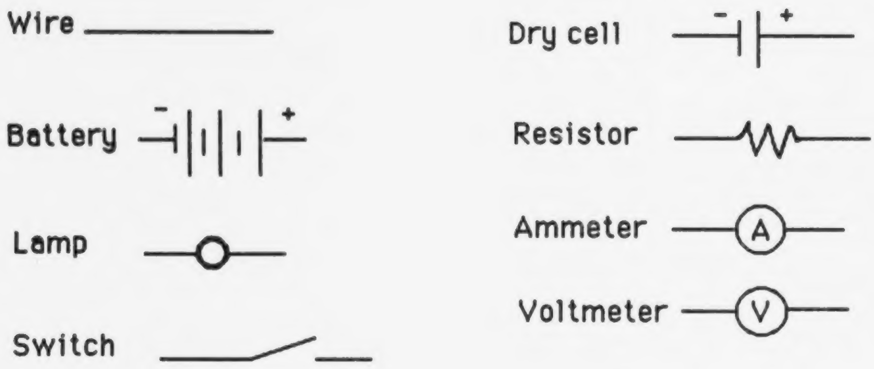
Answer -- A circuit that provides only one path through which the electric charges can flow. Students need to understand how to wire their bulbs for a series circuit. Draw a diagram and have students fill in lines to represent the wiring.

What is a parallel circuit?

Answer -- A circuit that provides a path for each load. A circuit that allows the current to divide and go through each load or lamp. Students need to understand how to wire their bulbs for a parallel circuit. They will wire the switch in series with the dry cell but the bulbs are to be parallel. Draw a diagram and have students fill in lines to represent the wiring.

What is a schematic diagram?

Answer -- A schematic diagram is a simplified sketch of an electric circuit, using symbols to represent the parts of the circuit. Schematics require very little space on a page, and symbols have general meanings. Review the following with students:



PROCEDURE 1: SERIES CIRCUIT

1. Connect three lamps, a switch, and a 6 volt battery in series. Be sure your connections are tight.

   Describe the brightness of the lamps.

Answer -- They are very dim.

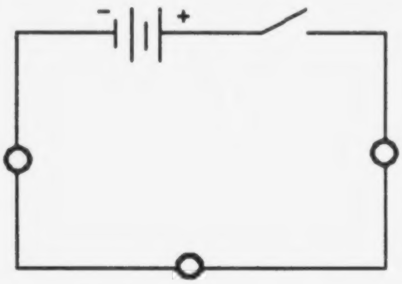
2. Loosen one bulb so that it goes out. **What happens to the other lamps in the circuit?**

Answer -- They all go out.

   How do you explain this result?

Answer -- Loosening the bulb breaks the circuit. Current cannot flow through an incomplete circuit.

3. Draw a schematic diagram of your series circuit, using the appropriate symbols.



PROCEDURE 2: PARALLEL CIRCUITS

1. Connect the three lamps in parallel to the switch and dry cell.
   How does the brightness of the parallel lamps compare with the brightness of the lamps in series?

Answer -- Lamps connected in parallel are brighter.

Why is the amount of light different when the lamps are connected in parallel?

Answer -- Lamps in parallel receive more current than lamps in series. The parallel arrangement divides the current so it goes through each lamp in equal quantities if the lamps are identical. Each will glow with equal brilliance. In the series arrangement, the same current exists in each lamp, since every electron that goes from lamp 1 to 2 must also go from lamp 2 to 3. Essentially, current in series must be shared.

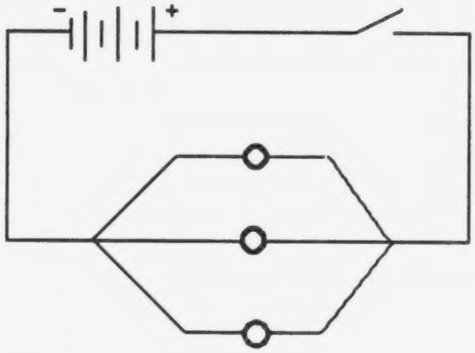
2. Loosen one bulb so that it goes out. **What happens to the other lamps in the circuit?**

Answer -- They remain lit.

How do you explain this result?

Answer -- Each lamp acts as a separate circuit.

3. Draw a schematic diagram of this parallel circuit, using the appropriate symbols.



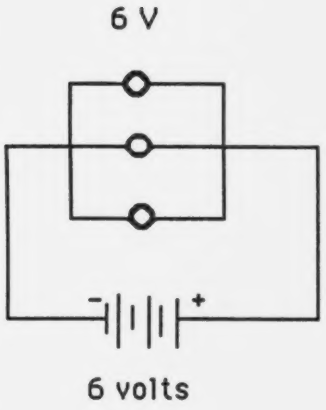
CONCLUSION

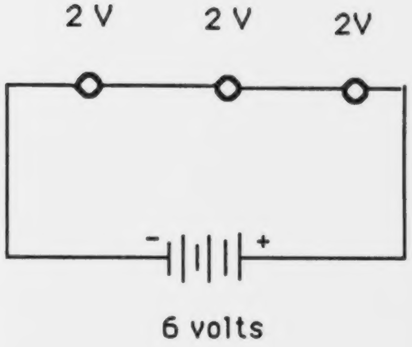
Compare the amount of light produced by lamps connected in series with the same lamps connected in parallel, using the same power source. Explain.

Answer -- The amount of light produced by lamps connected in parallel is greater (more brilliant) than the same lamps connected in series because the parallel connection allows each lamp to have its own circuit. Therefore, it receives more current. The series connection has only one circuit and the lamps share the same current.

POSTLABORATORY DISCUSSION

Draw a schematic for the parallel and series circuits studied in this lab on the board.





In which arrangement, series or parallel, does each lamp have the same voltage across its terminals?

Answer -- Parallel

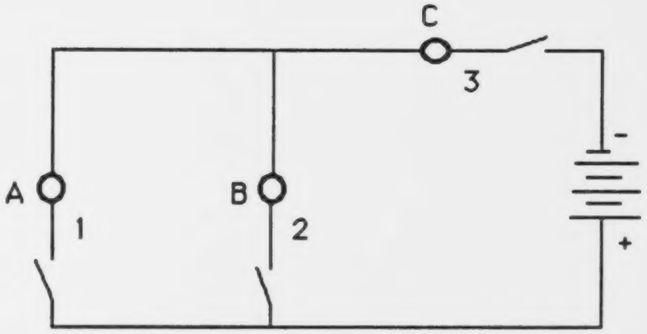
In which arrangement does each lamp receive the same current?

Answer -- Series

In which arrangement is the total resistance the greatest?

Answer -- Series. All of the current must pass through each lamp. The resistance of lamp 1 adds to lamp 2 and to lamp 3 to get the total resistance.

In the following circuit, which lamps will go out if a switch at 1 is opened? If a switch at 2 is opened? If a switch at 3 is opened?



Answer -- Lamp A is a branch in a parallel circuit. It is the only lamp controlled by switch 1.

Lamp B is a branch in a parallel circuit. It is the only lamp controlled by switch 2.

Switch 3 is in series with the dry cell and will control all three lamps. Lamp C will be controlled by switches 1 and 2 only if they are both open and/or closed at the same time.

HOW DO SERIES AND PARALLEL CIRCUITS WORK?

Laboratory Exercise

--for the student--

PURPOSE

The purpose of this exercise is to demonstrate the difference between series and parallel circuits.

MATERIALS

6 volt dry cell or DC power supply	Switches
3 light bulbs with sockets	Insulated copper wire for connections

PROCEDURE 1: SERIES CIRCUIT

1. Connect three lamps, a switch, and a 6 volt battery in series. Be sure your connections are tight.

   Describe the brightness of the lamps.

2. Loosen one bulb so that it goes out. **What happens to the other lamps in the circuit?**

   How do you explain this result?

3. Draw a schematic diagram of your series circuit, using the appropriate symbols.

PROCEDURE 2: PARALLEL CIRCUITS

1. Connect the three lamps in parallel to the switch and dry cell.

How does the brightness of the parallel lamps compare with the brightness of the lamps in series?

Why is the amount of light different when the lamps are connected in parallel?

____

____

2. Loosen one bulb so that it goes out. **What happens to the other lamps in the circuit?**

____

How do you explain this result?

____

____

3. Draw a schematic diagram of this parallel circuit, using the appropriate symbols.

CONCLUSION

Compare the amount of light produced by lamps connected in series with the same lamps connected in parallel, using the same power source. Explain.

____

____

____

____

____

ELECTRIC CIRCUITS

Laboratory Exercise
--for the teacher--

PURPOSE

The purpose of this lab activity is to discover the relationship between voltage, current, and resistance and solve for resistances using Ohm's Law. The student will find the resistance for 2 separate resistors and the total resistance for 2 resistors connected in series and in parallel.

MATERIALS (per lab group)

Dry cell or DC power supply*
6 copper wires (for connections)
A 2-ohm resistor
A 5-ohm resistor
Voltmeter
Ammeter
Switch

If your dry cells are old, power supplies should be used.

**Since most power supplies have a range of 1.5 to 6 volts, it is often suggested to use 2-ohm, 5-ohm, or 10-ohm resistors. On one hand, higher valued resistances tend to develop ammeter readings too low for the students to interpret. On the other hand, higher resistances give more accurate results. For dry cells, 2 and 5 ohms may be too low because of the internal resistance of the battery. When the external resistance (which you know) is similar to the internal resistance of the battery (which you are usually not aware of), the resistance may be double what you think it is. Consequently, when you compute the current using Ohms law (V = resistance x current), it may be off by a factor of two, which will confuse and frustrate you and the students. It is best to use large resistors and sensitive ammeters for this lab activity.

PRELABORATORY DISCUSSION

Review how to read the meter scales, especially if multi-meters are used. Remind students that ammeters are low resistance instruments and are connected in series; voltmeters are high resistance instruments and are connected in parallel. Remind students to connect negative terminals to the negative side of the circuit and positive terminals to the positive side of the circuit.

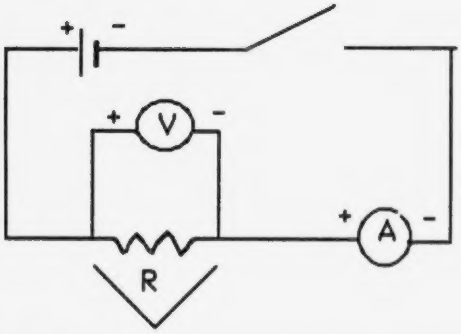
Wires, conductors, and appliances offer resistance to the flow of charges. This resistance is measured in units called **ohms.** You are to find resistances by calculations and compare them with the known resistances as printed on the resistors. You will use the same data table for all three procedures.

PROCEDURE 1: FIND THE RESISTANCE OF 2 SEPARATE RESISTORS

1. Read the value of resistance printed on your resistors and record on your data table. Let the one with the lowest number of ohms be R_1 and the one with the higher number of ohms be R_2.

2. Set up a simple electric circuit with one dry cell, a switch, ammeter, and resistor R_1 in series.

Remember to place the ammeter with the positive (+) terminal on the positive (+) side of the circuit. (See diagram at the bottom of this page for help.)



Resistors are to be inserted between these points in parallel with the voltmeter.

3. Connect the voltmeter across and parallel to resistor R_1.

4. Close the switch. Read the 2 meters. Record the volts and amperes on the data table. Open the switch.

5. Remove resistor R_1 and insert resistor R_2 at the same point in the circuit.

6. Close the switch. Read and record the volts and amperes on the data table. Open the switch.

DATA TABLE

Resistors	Volts	Amperes	Ohms (calculated)
$R_1 =$			
$R_2 =$			
$R_1 + R_2$ (in series)			
R_1 & R_2 (in parallel)			

What was the effect of the two different resistors, R1 and R2, on the voltage?

Answer -- The voltage is essentially the same. The points of connection across the resistor are the same as the terminals of the dry cell, when considering a single resistor in a simple circuit.

Which resistor--the one of less ohms or the one of more ohms--allowed more current (amperes) to flow through it? What seems to be the relationship between the current and the resistance?

Answer -- The one with less resistance (R_1) allowed more current to flow through it. As the resistance increases, the amount of current decreases (inverse relationship).

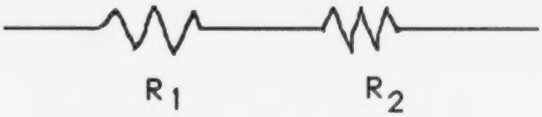
The relationship between resistance and current is called an **inverse** relationship. The relationship between current and volts is called a **direct** relationship. These relationships may be expressed in an equation as:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \quad \text{or rearranged:} \quad \text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$$

This relationship is called **Ohm's Law.** Use Ohm's law and solve for R_1 and R_2. Show your calculations here. Then record them on the data table. **How do your calculations compare with the known values for ohms as printed on your resistors?**

Answer -- Students should show their calculations in this space. Their calculated value for resistance should agree very closely with the value printed on the resistors.

PROCEDURE 2: FIND THE TOTAL RESISTANCE FOR 2 RESISTORS IN SERIES



1. Leave the circuit as you have it set up, but insert both R_1 and R_2 connected in series. See the diagram above for the connections in series.
2. Close the switch. Read and record the number of volts and amperes. Open the switch.
3. Use Ohm's Law and find the total resistance for both resistors connected in series. Record on the data table.

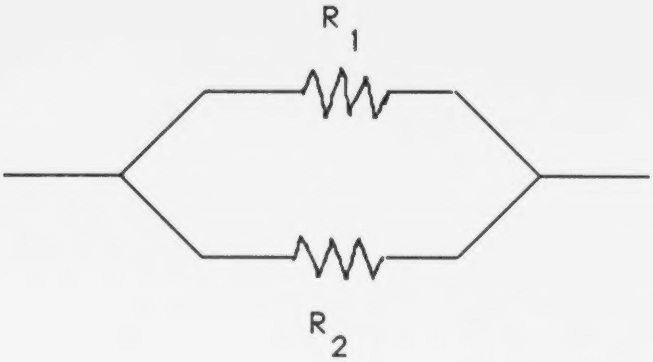
How does this total resistance compare with the sum of the two separate resistors? Therefore, how do you find the total resistance for resistors connected in series?

Answer -- The sum of the two separate resistors should be equal or very close to the total resistance found by using Ohm's Law and by adding the printed values of the two resistors. Students should be able to conclude that the total resistance of resistors connected in series is equal to the sum of the separate resistors.

$$R_T = R_1 + R_2 + R_3 + \ldots + R_n$$

PROCEDURE 3: FIND THE TOTAL RESISTANCE FOR 2 RESISTORS IN PARALLEL

1. Remove the R_1 and R_2 connected in series and arrange them in parallel.



2. Insert the two parallel resistors into the circuit.

3. Close the switch. Read and record the volts and amperes. Open the switch.

4. Use Ohm's Law and find the total resistance for 2 resistors connected in parallel. Record on the data table.

   How does this total resistance compare with the total resistance of R_1 and R_2 connected in series? ...of R_1 alone? ...of R_2 alone?

Answer -- Student data should indicate the total resistance of resistors connected in parallel is less than the same resistors connected in series and is less than the individual resistors alone.

Which connection of resistors--in series or in parallel--allows more current to flow through?
Answer -- Parallel connections allow more current to flow through.

CONCLUSION

1. How can resistance be determined by reading the voltmeter and the ammeter?

Answer --Resistance can be determined by dividing the voltmeter reading by the ammeter reading. (Ohm's Law)

2. What seems to be the advantage of connecting resistances in parallel?

Answer -- The total resistance of a parallel connection is less than that of any of the resistors in the connection. This is true because the conductors in parallel provide several paths for the current.

POSTLABORATORY DISCUSSION

Review the lab and conclusion questions with the students. Explain how to solve for the total resistance by using the reciprocals. Use the values printed on the resistors and solve for the total resistance using the reciprocals. Have students compare this value with the total resistance using Ohm's Law.

Example: What is the total resistance if R_1 and R_2 are connected in parallel? $R_1 = 2$ ohms and $R_2 = 5$ ohms.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n}$$

$$1/R_T = (1/2) + (1/5)$$

$$= (5/10) + (2/10)$$

$$= 7/10$$

Reciprocal of 7/10 is 10/7 so the total resistance is 1.42 ohms. Remember the high internal resistance of the battery may give results far from the ideal unless large value resistors are used. It is a pay off between good results that agree with theory and convenience of reading meters.

ELECTRIC CIRCUITS

Laboratory Exercise
--for the student--

PURPOSE

The purpose of this lab activity is to discover the relationship between voltage, current, and resistance and solve for resistances using Ohm's Law. The student will find the resistance for 2 separate resistors and the total resistance for 2 resistors connected in series and in parallel.

MATERIALS (per lab group)

Dry cell or DC power supply	A 5-ohm resistor	Switch
6 copper wires (for connections)	Voltmeter	
A 2-ohm resistor	Ammeter	

PROCEDURE 1: FIND THE RESISTANCE OF 2 SEPARATE RESISTORS

1. Read the value of resistance printed on your resistors and record on your data table. Let the one with the lowest number of ohms be R_1 and the one with the higher number of ohms be R_2.

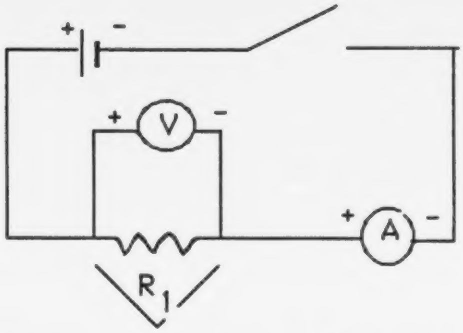
2. Set up a simple electric circuit with one dry cell, a switch, ammeter, and resistor R_1 in series.

Remember to place the ammeter with the positive (+) terminal on the positive (+) side of the circuit and the negative (-) terminal on the negative side of the circuit (-). This simple circuit is the main circuit, you will only need to change the resistors. (See diagram on the next page for help)

You will use the following data table in all procedures of this lab.

DATA TABLE

Resistors	Volts	Amperes	Ohms (calculated)
R_1 =			
R_2 =			
$R_1 + R_2$ (in series)			
R_1 & R_2 (in parallel)			



Resistors are to be inserted between these points in parallel with the voltmeter.

3. Connect the voltmeter across and parallel to resistor R_1.

4. Close the switch. Read the 2 meters. Record the volts and amperes on the data table. Open the switch.

5. Remove the resistor R_1 and insert the resistor R_2 at the same point in the circuit.

6. Close the switch. Read and record the volts and amperes on the data table. Open the switch.

   What was the effect of the two different resistors, R1 and R2, on the voltage?

____

____

Which resistor--the one of less ohms or the one of more ohms--allowed more current (amperes) to flow through it? What seems to be the relationship between the current and the resistance?

____

____

The relationship between resistance and current is called an **inverse** relationship. The relationship between current and volts is called a **direct** relationship. These relationships may be expressed in an equation as:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \qquad \text{or rearranged:} \qquad \text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$$

This relationship is called **Ohm's Law.**

Use Ohm's law and solve for R_1 and R_2. Show your calculations here. Then record them on the data table. **How do your calculations compare with the known values for ohms as printed on your resistors?**

____

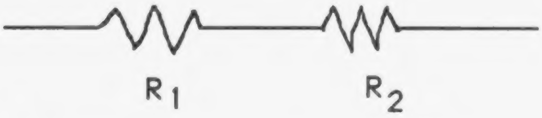
____

____

____

PROCEDURE 2: FIND THE TOTAL RESISTANCE FOR 2 RESISTORS IN SERIES

1. Leave the circuit as you have it set up, but insert both R_1 and R_2 connected in series. See the diagram for the connections in series.



2. Close the switch. Read and record the number of volts and amperes. Open the switch.
3. Use Ohm's Law and find the total resistance for both resistors connected in series. Record on the data table.

   How does this total resistance compare with the sum of the two separate resistors? Therefore, how do you find the total resistance for resistors connected in series?

____

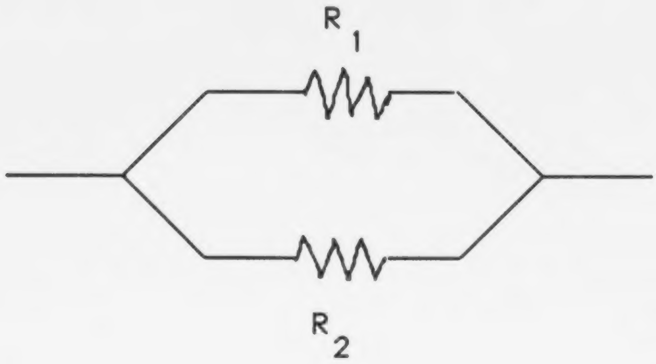
____

Write an equation for finding the total resistance of 3 or more resistors connected in series.

____

PROCEDURE 3: FIND THE TOTAL RESISTANCE FOR 2 RESISTORS IN PARALLEL

1. Remove the R_1 and R_2 connected in series and arrange them in parallel. See the diagram for the parallel connections.



2. Insert the two parallel resistors into the circuit.

3. Close the switch. Read and record the volts and amperes. Open the switch.

4. Use Ohm's Law and find the total resistance for 2 resistors connected in parallel. Record on the data table.

   How does this total resistance compare with the total resistance of R1 and R2 connected in **series? ...of R_1 alone? ...of R_2 alone?**

   ___

   ___

   Which connection of resistors--in series or in parallel--allows more current to flow through?

   ___

   ___

CONCLUSION

1. How can resistance be determined by reading the voltmeter and the ammeter?

   ___

   ___

   ___

   ___

2. What seems to be the advantage of connecting resistances in parallel?

   ___

   ___

   ___

   ___

STICKY ELECTRICITY

Laboratory Exercise
--for the teacher--

PURPOSE

The purpose of this lab activity is to make an electromagnet and to discover the factors that determine its strength.

MATERIALS

2 dry cells (1.5 volts)
Insulated copper wire (about 1.5 meters long) with ends stripped
2 short wires (to make connections between dry cells and switch)
Container of tacks or steel straight pins
2 soft iron rods or iron spikes
Doorbell or buzzer (for post lab discussion; optional)
Magnetic compass

In the construction of an electromagnet, **use iron not steel**. Some steel will become permanent magnets and will not "turn off"; they are not electromagnets in that once magnetized they stay magnetized.

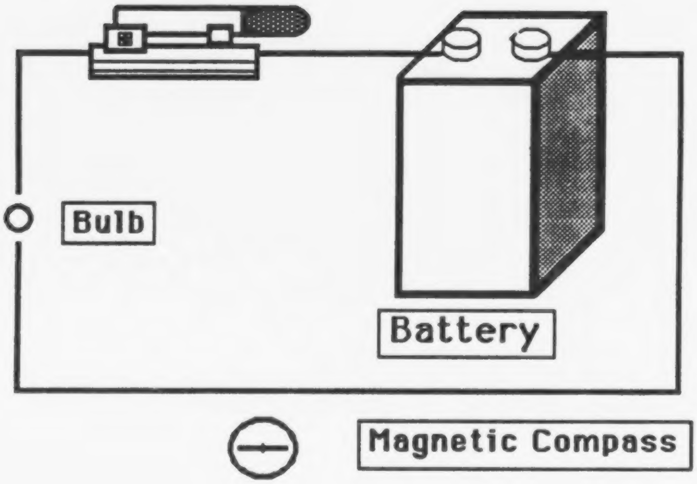
PRELABORATORY DISCUSSION

In 1820, a Danish physicist Hans Oersted accidentally discovered that an electric current produces a magnetic field. In 1825, William Sturgeon, an English electrician, demonstrated that an iron core makes a coil's magnetic field stronger. An American physicist, Joseph Henry, built the first practical electromagnet in 1827. Today electromagnets are used in many appliances - washing machines, dryers, tape and video players, vacuum cleaners, fans, and clocks to name a few. They are also used to drive electric doorbells, buzzers, and relays. Powerful industrial electromagnets lift heavy pieces of scrap iron. Huge electromagnets are used inside atom smashers to guide atomic particles along the desired path. Today we are going to make a simple electromagnet and discover the factors that determine its strength.

PROCEDURE 1: MAKING AN ELECTROMAGNET

1. Connect the long copper wire in a simple circuit with one dry cell and a switch.

2. Close the switch to allow the electricity to flow in the circuit. Place a magnetic compass near a part of the wire. **(Do not leave the switch closed for more than a few seconds at a time. This activity is very hard on dry cells).** This procedure will destroy dry cells and blow fuses in most power supplies. Therefore, we recommend placing a bulb in series so there is a load in the system.



What happens to the tack while the switch is closed and the current is allowed to flow? Explain your observation?

Answer -- There is a weak attraction between the wire and the small tack. The attraction is due to the magnetic field created by the electric current in the wire.

3. Wind the long copper wire around a soft iron rod. Wind until you have a total of 25 turns. Be careful not to kink the wire.

4. Connect the windings in a simple circuit with a switch and a dry cell.

5. Place one end of the rod in a container of small tacks and close the switch for about three seconds. Then open the switch.

Describe what happened when you closed the switch. Explain your observation.

Answer -- The rod attracts a few tacks. Closing the switch allows the electric current to flow and a magnetic field is created around the coil. (An electromagnet is formed.)

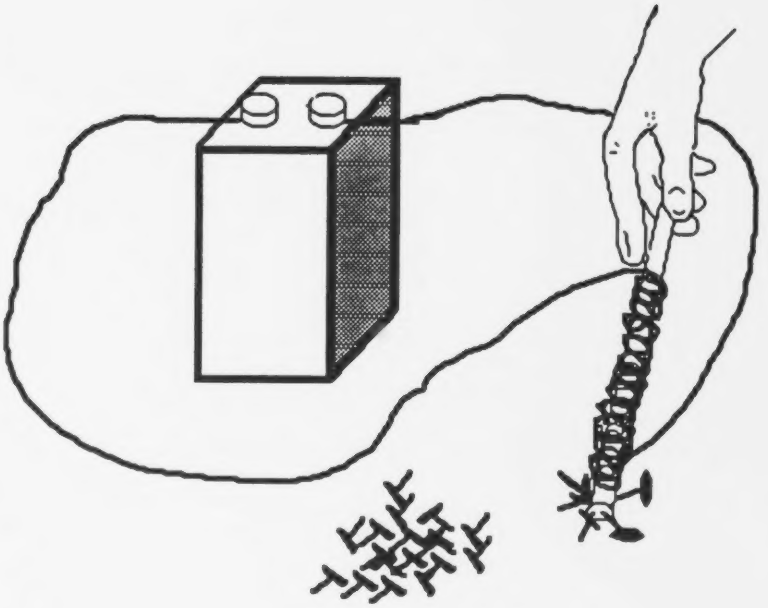
Describe what happened when you opened the switch. Explain your observation.

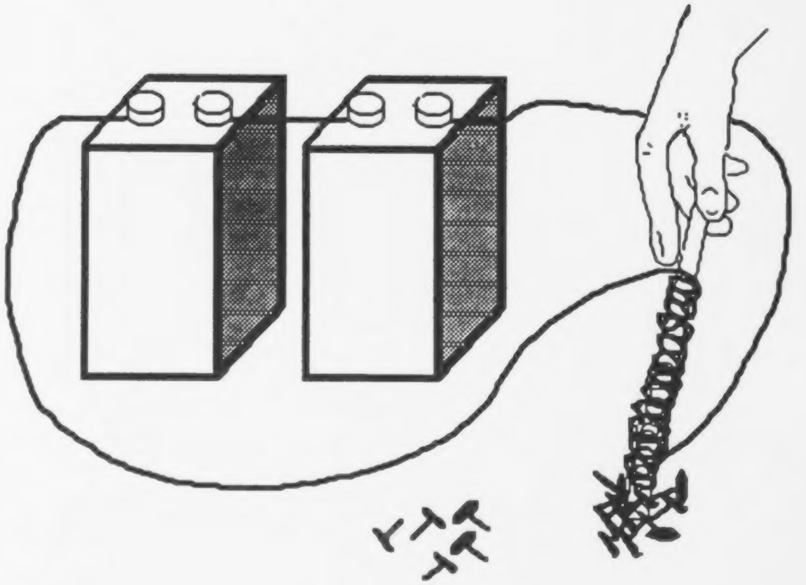
Answer -- The rod no longer attracts the tacks. Opening the switch stops the current so the coil loses its magnetic field.

An electromagnet must be made of what 2 things? It will be magnetic only under what condition?

Answer -- A coil of wire, and a source of current. A soft iron core makes the electromagnet stronger but is not an absolute must. The coil will become an electromagnet only if the current is permitted to flow.

PROCEDURE 2: FACTORS THAT DETERMINE THE MAGNETIC STRENGTH
1. Hook up your electromagnet as described in the data table on the next page.
2. Test each hook up by placing the rod in a container of tacks.





3. Count and record the number of tacks the electromagnet lifts.

Number of wire turns	Number of dry cells	Number of cores(nails)	Number of tacks picked up
25	1	0	
25	1	1	
25	2	1	
25	1	2	
50	1	1	
50	2	1	

What effect did the larger number of turns have on your electromagnet?

Answer -- The electromagnet picked up more tacks, became stronger.

What effect did the second dry cell have on your electromagnet?

Answer -- Increased the strength by increasing the amount of current.

What effect did the presence of a core have on your electromagnet?

Answer -- Increase the strength. The core becomes magnetized by induction. The result is that the total magnetic field due to coil plus the core is greater than that of the coil alone.

CONCLUSION

Look back over your lab activity and all of your data and observations. Answer each of the following questions.

1. What is an electromagnet made of?

2. What determines the strength of an electromagnet?

Answer -- An electromagnet consists of a coil through which an electric current is passed. Usually the coil is wound on an iron core. The strength of the electromagnet is directly proportional to the magnitude of the current and to the number of turns around the iron. Strength also depends on the type of magnetic core used. The more magnetically permeable the core, the greater the strength. In this lab students do not actually look at permeability as a factor. They only discover that the presence of a soft iron core increases the strength. If you wish to add permeability, have students substitute a glass rod for the iron core and observe the difference.

POSTLABORATORY DISCUSSION

Review the lab and discuss the conclusion questions. Have students apply what they learned about electromagnets by explaining its use in doorbells or buzzers.

Hand out a doorbell or buzzer to each lab group or display a model for all to see. Identify the parts of the doorbell (armature, gong, contact screw, spring, and electromagnet). Discussion might include the following questions:

1. What is the electromagnet in this doorbell made of?

Answer -- The electromagnet consists of a coil of wire wound around a soft iron core and a source of electric current to make the coil and core magnetized.

2. What happens to the coil and core when the circuit is complete?

Answer -- The coil and core become magnetized. They become an electromagnet.

3. What effect does the electromagnet have on the armature?

Answer -- The electromagnet attracts the armature, pulling it toward the gong. The bell sounds.

4. What happens to the circuit when the armature leaves the contact screw?

Answer -- The circuit is broken.

5. What happens to the electromagnet when the circuit is broken?

Answer -- The electromagnet loses its power or magnetism.

6. What happens to the armature when the electromagnet loses its magnetic attraction?

Answer -- The armature springs back to make contact with the contact screw.

7. When the armature hits the contact screw, what happens to the circuit?

Answer -- The circuit is complete, the electromagnet is turned on, the cycle starts over.

STICKY ELECTRICITY

Laboratory Exercise

--for the student--

PURPOSE

The purpose of this lab activity is to make an electromagnet and to discover the factors that determine its strength.

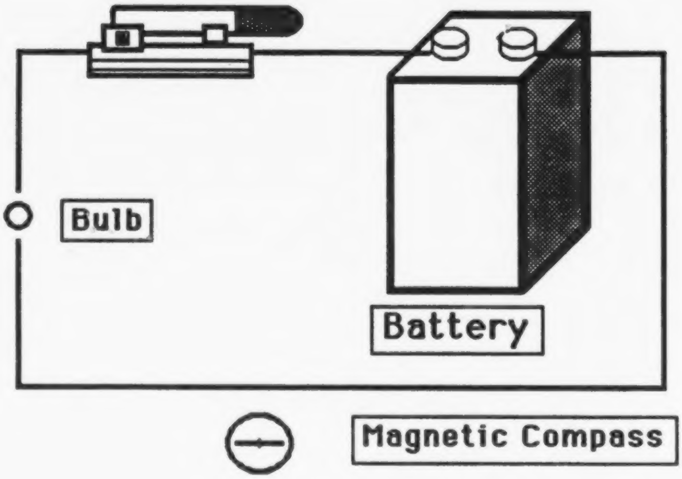
MATERIALS

2 dry cells (1.5 volts)
Insulated copper wire (about 1.5 meters long) with ends stripped
2 short wires (to make connections between dry cells and switch)
Container of tacks or steel straight pins
2 soft iron rods or iron spikes
Magnetic compass

PROCEDURE 1: MAKING AN ELECTROMAGNET

1. Connect the long copper wire in a simple circuit with one dry cell and a switch.

2. Close the switch to allow the electricity to flow in the circuit. Place a magnetic compass near a part of the wire. **(Do not leave the switch closed for more than a few seconds at a time. This activity is very hard on dry cells.)**



What happens to the tack while the switch is closed and the current is allowed to flow? Explain your observation.

____

____

3. Wind the long copper wire around a soft iron rod. Wind until you have a total of 25 turns. Be careful not to kink the wire.

4. Connect the windings in a simple circuit with a switch and a dry cell.

5. Place one end of the rod in a container of small tacks and close the switch for about three seconds. Then open the switch.

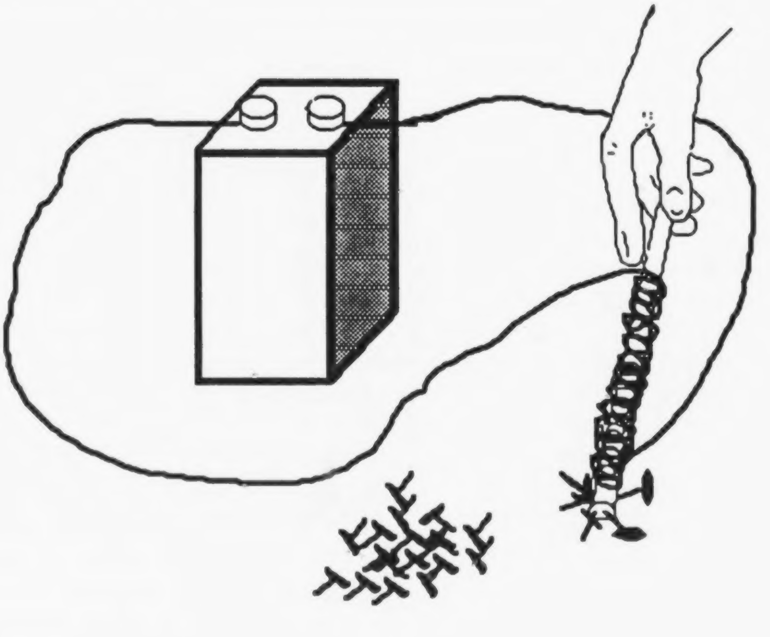
Describe what happened when you closed the switch. Explain your observation.

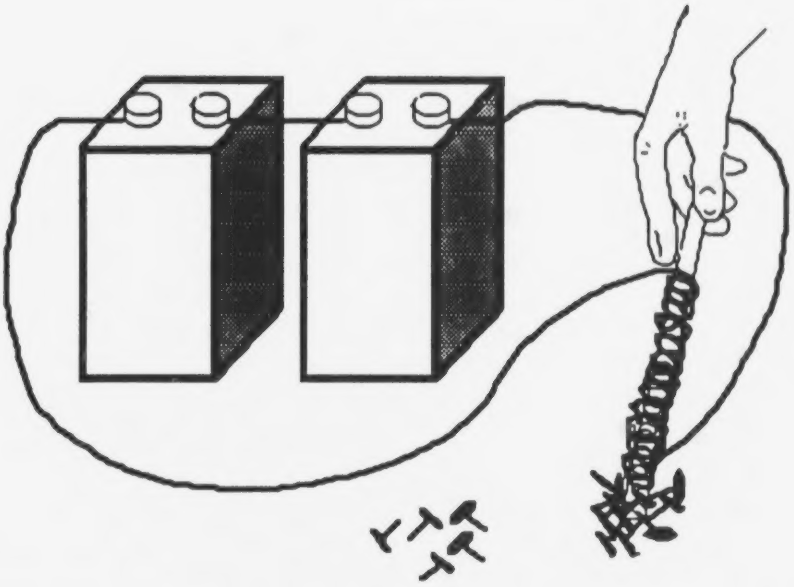
Describe what happened when you opened the switch. Explain your observation.

An electromagnet must be made of what 2 things? It will be magnetic only under what condition?

PROCEDURE 2: FACTORS THAT DETERMINE THE MAGNETIC STRENGTH

1. Hook up your electromagnet as described in the data table on the next page.
2. Test each hook up by placing the rod in a container of tacks.





3. Count and record the number of tacks the electromagnet lifts.

Number of wire turns	Number of dry cells	Number of cores (nails)	Number of tacks picked up
25	1	0	
25	1	1	
25	2	1	
25	1	2	
50	1	1	
50	2	1	

What effect did the larger number of turns have on your electromagnet?

What effect did the second dry cell have on your electromagnet?

What effect did the presence of a core have on your electromagnet?

CONCLUSION

Look back over your lab activity and all of your data and observations. Answer each of the following questions.

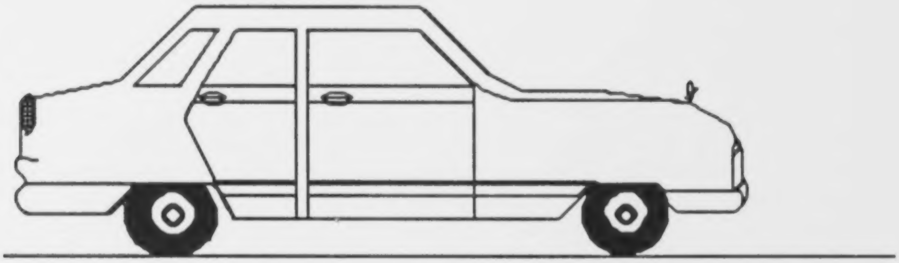
1. What is an electromagnet made of?

2. What determines the strength of an electromagnet?

Motion

Background Information

10



The person who is often given credit for being the first to seriously study motion is the Greek philosopher and scientist, Artistotle. Over 2000 years ago, he divided motion into two classes: **natural motion** and **violent motion.**

Natural motion occurred due to the "nature" of the body. According to Aristotle, every body had a proper place; if out of its proper place, it would somehow attempt to return there. This proper place was determined by its nature, In other words, if a rock, which is like this earth, was lifted above the earth and released, it would naturally fall back to the earth. Smoke, being like the sky, would rise to the sky. Large, heavy objects had a greater yearning to return to their natural state than small, light objects so they would fall at a faster rate.

Violent motion was imposed and was the result of a push or pull. An imposed external force was needed to lift a rock, row a boat, or shoot an arrow. Therefore, except for the celestial bodies, he considered the normal state to be one of rest.

The foremost scientist of the sixteenth century, **Galileo Galilei,** said that a person who is ignorant about motion is ignorant about nature. But, he refuted Aristotle's classification of motion as natural and violent. Disregarding the small effect of air resistance, when objects of differing weights were released at the same time (as from Leaning Tower of Pisa) they struck the ground at the same time. Even with many witnesses, he was unable to convince many that speed was not proportional to weight. Galileo went on to say that a force was not needed to maintain a body's motion, but, in fact, he suggested if no external force acted upon the body, it would keep moving in a straight line forever.

He rolled a ball down an inclined plane and noticed that it gained speed. When the ball rolled up an inclined plane, speed was lost. He observed that a ball rolled down one inclined plane would roll up another inclined plane almost until it reached the original height. As the slope of the second inclined plane was decreased, the ball had to roll farther but would still very nearly reach the original height. He reasoned that if a ball were to roll on a horizontal plane that it would not stop. The reason the ball does stop in actuality is not because of its natural tendency, but because of **friction.**

Galileo's generalizations concerning falling objects using an inclined plane by "dilution of motion" is discussed in Dialogues Concerning Two New Sciences. He said by reducing the slope angle, the motion was "diluted". And the measurement could be made more accurately with a higher degree of reproducibility because the time interval was larger. The steeper an inclined plane, the less the motion was "diluted", a greater distance was covered in a given time, and the more closely the speed resembled a free-falling object. His experimental values closely approached what is now called the acceleration due to gravity (9.80 meters/sec^2).

TERMINOLOGY

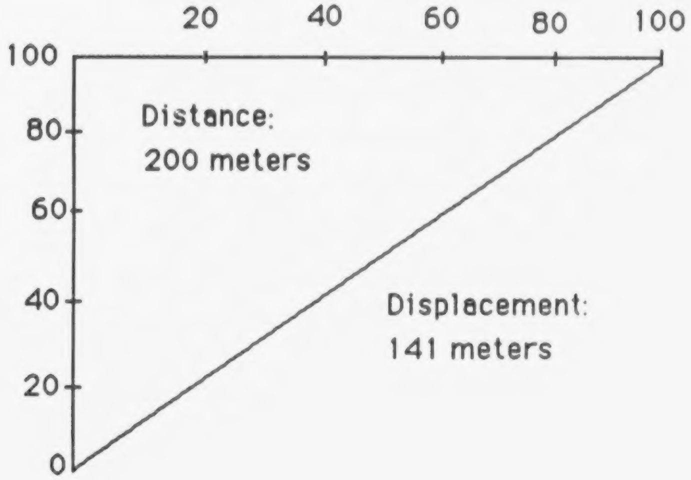
What is **motion**? A bird flies, a fish swims, a leaf flutters to the ground, a ball is thrown, and a rubber band is stretched. In each of these examples motion was involved. **Motion** can be described as a **change of position.** When a body moves or is moved from one position to another, a change in distance is usually noted. However, this motion is called relative motion because it is relative to some fixed object. When you take off in an airplane, the airplane moves away from the airport. The airport is fixed in a reference frame attached to the earth. In this reference frame the airplane moves away from the airport. The airport is called **a reference point.** A frame of reference is a set of reference points that are fixed relative to each other. In this airplane/airport example there are two reference frames -- one inside the airplane and one on the surface of the earth.

While sitting in a chair it appears that you are not moving. But the earth is rotating on its axis once every 24 hours, which is over 1046 miles per hour at the equator! The earth is also precessing on its axis and revolving around the sun. (If you were to calculate our speed in one revolution around the sun, it would be approximately 66,705 miles per hour.) As if that isn't enough, the solar system is revolving around the Milky Way. Of course the Milky way isn't standing still either. Determining the motion of an object is much more complicated than it may seem, which is why it is necessary to establish a frame of reference.

Consider the folowing situation. You are in a train. When you look out the window, all you can see is another train. Both trains are travelling in the same direction and at the same speed. Without any other reference points, your frame of reference would indicate that you are not moving. You look out a second time and see the other train whizzing by in the opposite direction. Which train is moving . . . . or are both trains moving? You can't tell without some other points of reference (like some buildings, trees, or the ground).

In the above paragraphs two parameters (variables) of motion have been mentioned: **distance** and **time.** The ratio of distance to time is called **speed.** Speed is described as the rate of changing position. In other words, it is not sufficient to say that you traveled 100 meters. How long did it take? Nine seconds and you just broke the world record; nine months and you may need help. This also brings us to another distinction. Distance and displacement are not the same thing.

Distance is the length of a path that an object travels. **Displacement** on the other hand measures distance and direction. For example, someone could walk around a three-mile jogging track. The distance traveled would obviously be three miles, but if the person ended up at the same point that he started, his displacement would be zero. Someone else who walked forward for 100 meters, turned 90 degrees to the right, and walked another 100 meters would have walked a total of 200 meters with a displacement of 141 meters. Please see the diagram given below:



Direction is also important when discussing speed and velocity. Speed was roughly defined as the rate of changing position. In a formula, it would be written as s=d/t. Velocity is often used interchangeably for speed, but that is not truly accurate because velocity is the rate of motion in a certain direction. Speed is called a **scalar** quantity because it describes only the magnitude (how much?). Examples of scalar quantities are mass, volume, temperature, and speed (5.2 m/s). **Vector** quantities give a more complete description because both the magnitude AND the direction are included. Displacement, magnetic fields, acceleration, and velocity (5.2 m/s, northeast) are examples of vector quantities. The formula used to determine average velocity is v=x/t. It is essentially identical to the formula for speed except "x" is used for displacement (a vector quantity) instead of "d" for distance.

Caution! The "x" in the formula v = x/t is not the coordinate x. Instead it is the change in position of the moving object. For example, an object placed at x = 4 on a chalkboard scale would have a non zero value for x over t, yet the velocity of this object would be zero.

The formula v=x/t is that for **average** velocity, which is the ratio of the total displacement to the total time interval. It could also be described as the average of all the **instantaneous** velocities. To keep it relatively simple, let's call the instantaneous velocity the velocity at one instant of time. If the velocity is constant, then the instantaneous velocity would equal the average velocity. However, if the velocity is not constant, the two values are not interchangeable.

When describing constant velocity as opposed to changing velocity, a new term is introduced: **acceleration.** While speed and velocity are both rates of motion, acceleration is the rate of change of velocity. As with velocity, acceleration can be instantaneous or average. To find the average acceleration, find the difference in the final velocity from the original and divide this by the time it took to make that change in velocity. The resulting units would be m/s^2. It is easy to think of square centimeters, but what is a square second?

An acceleration of 9.80 m/s^2 means that an object's velocity would increase 9.80 m/s for each second. Similarly, if the velocity changed 10 km/hr in 1.0 second, the acceleration would be 10 km/hr/s. This is sometimes not as difficult to understand as a square second. Another approach is to use numbers instead of units. Remember, acceleration is the ratio of velocity (m/s) to time (s). So rather than have the students worry about "m/s" divided by "s" to give "m/s^2", have them divide 1/4 by 4. (1/4 ÷ 4 = 1/4 x 1/4 = 1/16). Isn't 1/16 the same as 1/(4)^2 ? Why?

The formula for average acceleration is:

$$\frac{\Delta V}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} = \frac{\text{final velocity - initial velocity}}{\text{final time - initial time}}$$

If v_i and t_i are both zero, then $a=v/t$. If v_f is less than v_i, a negative acceleration will occur (called deceleration). Remember acceleration, velocity, and position are all vectors. The algebraic sign on a vector specifies only the direction of that vector. Deceleration is a very special term, applying only to those cases where an object comes to a halt and remains at rest. If, on the other hand the object does not remain at rest after stopping, what was deceleration becomes acceleration. The acceleration may not have changed -- for example gravity -- yet we may imply a change by arbitrarily changing the algebraic sign at the point where the object comes to a halt. For example, if you throw an object up in the air it will slow down, stop, and then speed up as it falls back toward you. During this entire motion the acceleration has not changed.

Because velocity and acceleration are both vector quantities, acceleration can occur not only when the magnitude of the velocity changes but also if a change in direction takes place. A car that accelerates from zero to 80 km/hr and then decelerates back to zero on a straight road illustrates a change in velocity but not direction. Another car travels at a constant speed of 50 km/hr in a circle is accelerating due to change in direction. A third car attached to a roller coaster experiences acceleration due both to change in velocity and direction.

MOTION: FORMULAS and GRAPH

I. **Velocity**:

(A)

$$V_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

Δ means a change in
i means initial
f means final

if x_i and t_i both equal zero, then $v_{avg} = x/t$ (1)

(B) $v_{avg} = (v_f + v_i)/2$ [valid only for constant acceleration]

so if $v_i = 0$, then $v_{avg} = v_f/2$ (2)

II. **Acceleration:**

(C)

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

Δ means a change in

if v_i and t_i both equal zero, then $a_{avg} = v/t$ (3)
if $v_i \neq 0$ but $t_i = 0$, then $a = (v_f - v_i)/t$

by rearranging the terms: $v_f = v_i + at$ (4)

III. **Displacement:** by rearranging $\Delta x = v_{avg} \Delta t$ and

(D) $x_f - x_i = v_{avg} (t_f - t_i)$

if x_i and t_i both equal zero, then $x = v_{avg}t$ (1')

(E) $v_{avg} = (v_f + v_i)/2$, then $x = [(v_f + v_i)/2]\ t$

(F) since $v_f = v_i + at$, then $x = [(v_i + at + v_i)/2]\ t$

(G) by combining: $x = v_i t + 1/2(at^2)$ (5)

DATA FOR A BODY WITH CONSTANT VELOCITY

TIME (seconds)	SPEED (meters per second)	TOTAL DISTANCE TRAVELED (meters)	DISTANCE TRAVELED EACH SECOND (meters)
1	3	3.0	3.0
2	3	6.0	3.0
3	3	9.0	3.0
4	3	12.0	3.0
5	3	15.0	3.0
6	3	18.0	3.0
7	3	21.0	3.0
8	3	24.0	3.0
9	3	27.0	3.0
10	3	30.0	3.0

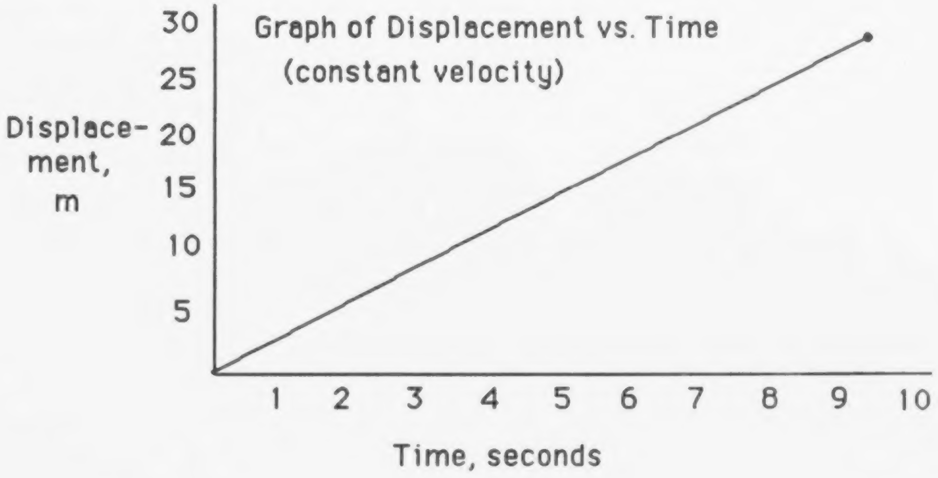
The above data chart shows the velocity to be a constant 3 m/s and the acceleration to be zero.

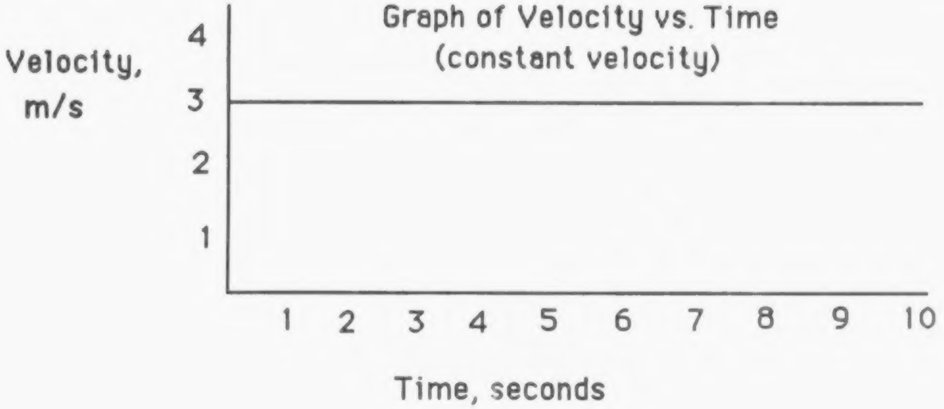
DATA FOR A BODY WITH CONSTANT ACCELERATION

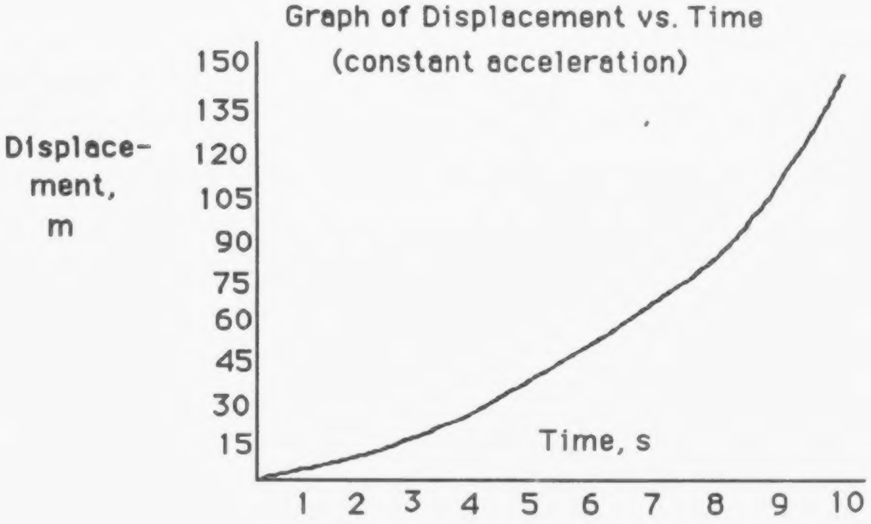
TIME (seconds)	SPEED (meters per second)	DISTANCE TOTAL DISTANCE TRAVELED (meters)	TRAVELED EACH SECOND (meters)
0	0	0.0	0.0
1	3	1.5	1.5
2	6	6.0	4.5
3	9	13.5	7.5
4	12	24.0	10.5
5	15	37.5	13.5
6	18	54.0	16.5
7	21	73.5	19.5
8	24	96.0	22.5
9	27	121.5	25.5
10	30	150.0	28.5

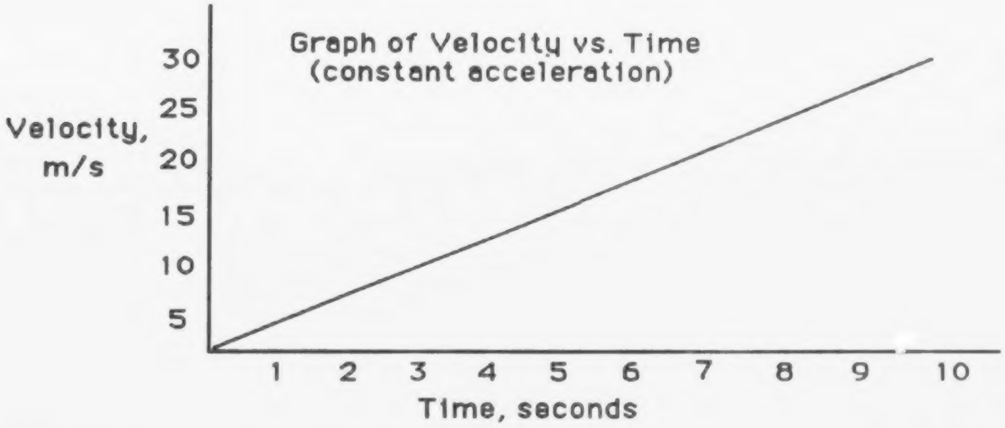
The above chart shows a constant acceleration of 3.0 m/s^2. This means that the velocity increases by 3 m/s each second.

Compare the graphs that follow:




Graph of Velocity vs. Time
(constant velocity)
Velocity, m/s
4
3
2
1
1
2
3
4
5
6
7
8
9
10
Time, seconds


Graph of Displacement vs. Time
(constant acceleration)
Displacement, m
150
135
120
105
90
75
60
45
30
15
Time, s
1
2
3
4
5
6
7
8
9
10


Graph of Velocity vs. Time
(constant acceleration)
Velocity, m/s
30
25
20
15
10
5
1
2
3
4
5
6
7
8
9
10
Time, seconds

MOTION ACROSS THE UNITED STATES

Paper and Pencil Exercise

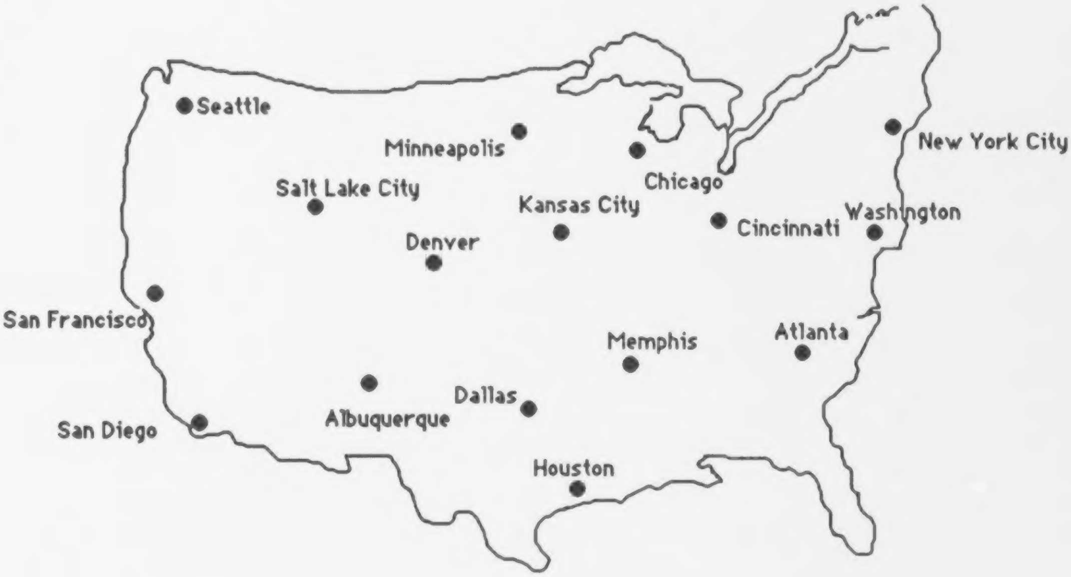
--for the teacher--

PURPOSE

This worksheet is designed to help the student become more comfortable with the formula used to calculate speed, distance, and time.

PROCEDURE

Use the map and tables below to answer the questions and problems. The distances are in kilometers. The times are in hours and minutes. (For example, the traveling time between Salt Lake City and Denver, 12:00, represents 12 hours and zero minutes.)


Seattle
Minneapolis
Salt Lake City
Chicago
Kansas City
Cincinnati
Washington
New York City
Denver
San Francisco
Memphis
Atlanta
Dallas
Albuquerque
San Diego
Houston

DISTANCE BETWEEN CITIES

From	To	Distance (in kilometers)
San Francisco	Salt Lake City	1210
Salt Lake City	Minneapolis	1910
Albuquerque	Dallas	1020
Denver	Kansas City	970
Memphis	Atlanta	600
Cincinnati	New York City	1050
Houston	Atlanta	1270

TIME BETWEEN CITIES

From	To	Time (in hours & minutes)
San Francisco	Albuquerque	20:20
Salt Lake City	Denver	12:00
Minneapolis	Chicago	7:25
Kansas City	Cincinnati	10:50
Chicago	New York City	14:40
Albuquerque	Houston	15:15
Atlanta	New York City	15:20

QUESTIONS

1. The speed limit is 88 km/hr. How long would it take you to drive from Atlanta to New York City?

Answer -- 15 hours and 20 minutes.

2. What is the distance between Minneapolis and Chicago? (The time shown is for traveling the speed limit, 88 km/hr.)

Answer -- 7:25 = 7 hours + (25 minutes x 1 hour/60 minutes) = 7.42 hours

$s = d/t$ AND $d = st$

$d = 7.42$ hours x 88 km/hour = 653 kilometers

3. Can you leave Atlanta at 10:30 a.m. and drive back to Houston by 10:00 p.m. without breaking the speed limit? Explain.

Answer -- No, because the distance is 1270 kilometers and the time is 11.5 hours. So, your average speed would need to be 110 km/hr.

4. What is the total distance and total time to drive from San Francisco to New York City (by the shortest possible route shown and averaging 88 km/hr)?

Answer -- The shortest route is from San Francisco to Salt Lake City (1210 km), then to Minneapolis (1910 km), through Chicago (653 km --from question #2) and finally stop in New York City (1291 km -- 14:40 = 14.25 hours, multiplied by 88km/hour).

The total distance is 5064 kilometers, which would require a total time of 57.55 hours or 57 hours and 32 minutes.

5. Two drivers leave Albuquerque at the same time. Joe drives to Houston, while Emerson to Kansas City. Both drivers travel at an average speed of 88 kilometers/hour. If it took Emerson 1 hour and 35 minutes longer to get to Kansas City than it did for Joe to reach Houston, then how far is it from Albuquerque to Kansas City?

Answer -- Emerson's total travel time is 1:35 plus 15:15 (time for Joe to travel from Albuquerque to Houston) which is 16:50 (or 16:83 hours).
16.83 hours x 88 kilometers/hour = 1481 kilometers

MOTION ACROSS THE UNITED STATES

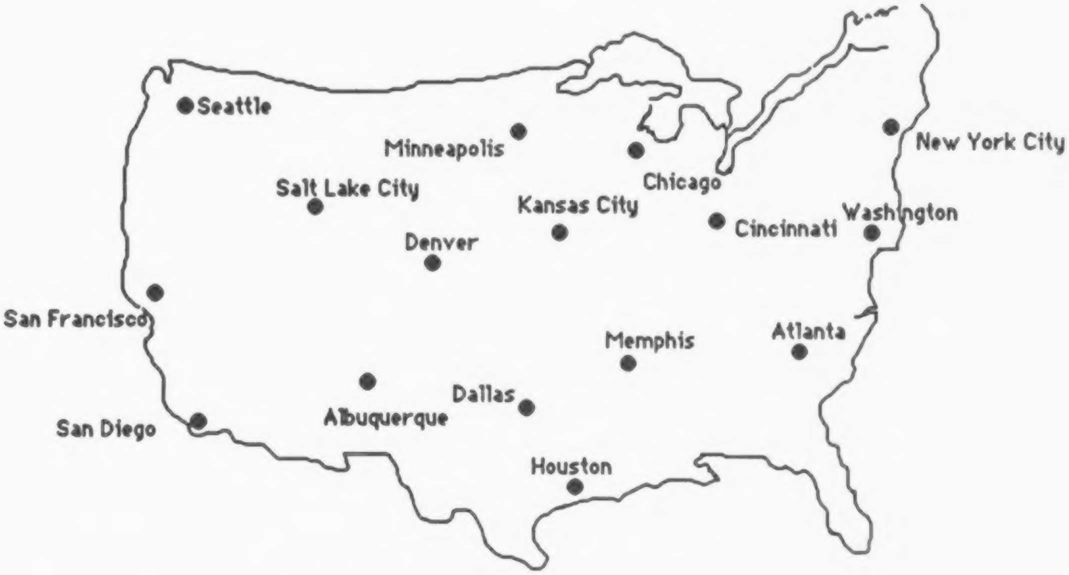
Paper and Pencil Exercise
--for the student--

PURPOSE

This worksheet is designed to help you to calculate speed, distance, and time.

PROCEDURE

Use the map and tables below to answer the questions and problems. The distances are in kilometers. The times are in hours and minutes. For example, the traveling time between Salt Lake City and Denver is 12:00, and it represents 12 hours and zero minutes.


Seattle
Minneapolis
Chicago
New York City
Salt Lake City
Kansas City
Cincinnati
Washington
Denver
San Francisco
Memphis
Atlanta
Dallas
Albuquerque
San Diego
Houston

DISTANCE BETWEEN CITIES

From	To	Distance (in kilometers)
San Francisco	Salt Lake City	1210
Salt Lake City	Minneapolis	1910
Albuquerque	Dallas	1020
Denver	Kansas City	970
Memphis	Atlanta	600
Cincinnati	New York City	1050
Houston	Atlanta	1270

TIME BETWEEN CITIES

From	To	Time (in hours & minutes)
San Francisco	Albuquerque	20:20
Salt Lake City	Denver	12:00
Minneapolis	Chicago	7:25
Kansas City	Cincinnati	10:50
Chicago	New York City	14:40
Albuquerque	Houston	15:15
Atlanta	New York City	15:20

QUESTIONS

1. The speed limit is 88 km/hr. How long would it take you to drive from Atlanta to New York City?

2. What is the distance between Minneapolis and Chicago? (The time shown is for traveling the speed limit, 88 km/hr.)

3. Can you leave Atlanta at 10:30 a.m. and drive back to Houston by 10:00 p.m. without breaking the speed limit? Explain.

4. What is the total distance and total time to drive from San Francisco to New York City (by the shortest possible route shown and averaging 88 km/hr)?

5. Two drivers leave Albuquerque at the same time. Joe drives to Houston, while Emerson to Kansas City. Both drivers travel at an average speed of 88 kilometers/hour. If it took Emerson 1 hour and 35 minutes longer to get to Kansas City than it did for Joe to reach Houston, then how far is it from Albuquerque to Kansas City?

MOTION FROM HERE TO ETERNITY

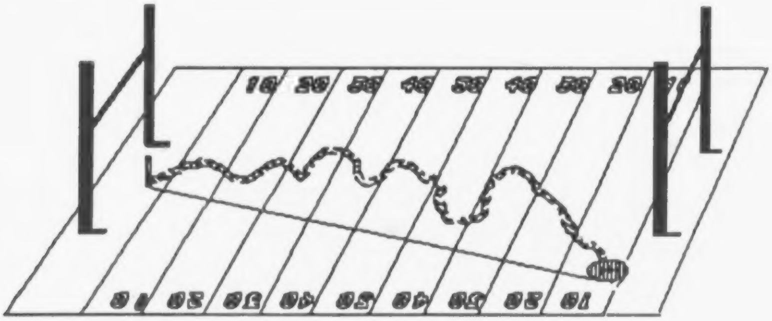
Demonstration

PURPOSE

This activity is designed to help the student differentiate between distance and displacement. Distance is the total path length, while displacement is the distance in a certain direction. **Displacement** is the distance between the initial and final positions.

MATERIALS

Long rope (at least 10 meters in length)
Tape (preferably contrast in color to the rope)
Meter stick
A large open area (gymnasium, football field . . .)



PROCEDURES

1. Use the meter stick to measure one meter from the end of the rope. Mark this spot on the rope with the colorful tape. Measure one meter intervals and mark them with the tape until the end of the rope.
2. Have one student hold one end of the rope on the ground, and the other student hold the rope in his/her hands. Have another student walk away from the first student. As the second student walks away, have him lay the rope down along his actual path. The class can count the meters as he goes. The number of meters of rope on the ground between the two students represents the total distance traveled.
3. Now have the second student pull the rope to remove the slack between him and the first student. The amount of rope now between the two students is the displacement for that direction.

When would the distance and displacement by equal?

Answer--Since displacement is the shortest distance between two points, as long as the path did not change direction, the distance would equal the displacement.

What are some examples of path patterns that would result in zero displacement?

Answer -- Any pattern that is a closed figure (circle, square, triangle, etc.) would result in zero displacement because there would be no difference between the starting and stopping points.

Repeat steps B and C with other students. (Suggest path patterns of a circle, zig-zag, etc.)

Can the distance be greater than the displacement?

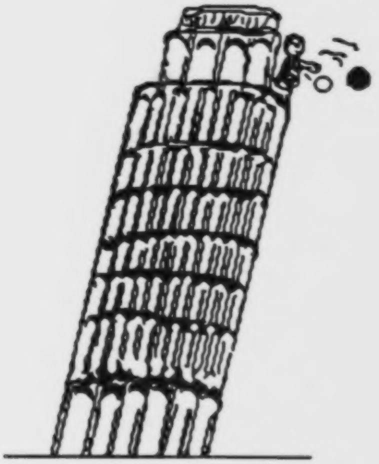
Answer- -Any time the direction is changed during some motion, the displacement will be less than the distance traveled because the displacement is the shortest distance between two points.

Can the displacement be greater than the distance?

Answer - - The displacement can be only as great as the distance, never more.

FREE FALL AND THE DOLLAR BILL

Demonstration



PURPOSE

Free fall is motion influenced only by gravity (air resistance is neglected). The first part of this demonstration is intended to show the student the misconceptions of motion according to Aristotle. It is modeled after Galileo's Leaning Tower of Pisa experiment. The second part involves calculating acceleration due to gravity. The final part is an application with reaction time.

MATERIALS

Tennis ball
Baseball
Meter stick
Stopwatch

According to Aristotle's view of natural motion, when a solid object is lifted above the surface of the earth, it will want to return to its natural position of rest (on the earth's surface). Furthermore, the more massive the object the faster it should fall.

PROCEDURE 1

1. The tennis ball and baseball are nearly the same size, but the baseball has more mass. (You might want to take the mass of each ball to establish a ratio, but a qualitative ratio will be sufficient.)

If the baseball weighs three times as much as the tennis ball, will it strike the ground three times faster (one-third the time it takes the tennis ball)?

2. With the tennis ball in one hand and the baseball in the other, lift both to the same height above the floor. Drop at the same instant.

Which ball hit the floor first? Are you able to explain why this is so?

Answer - - The baseball has about three times the mass of a tennis ball, so the earth's gravitational attraction for the baseball is three times that of the tennis ball. But, the massive baseball has more inertia (it is more sluggish in its motion) and requires three times the force to get it moving in the first place, it takes three times the force to accelerate an object with three times the mass, the net result is that the two balls hit the floor simultaneously.

PROCEDURE II

1. Given the average velocity is equal to the displacement divided by the time, algebraically rearranging the variables shows:

$$x = v_{avg}(t)$$

2. The average velocity can be determined by dividing the sum of the instantaneous final and initial velocities by two. (This is the same as adding a student's first and second test grades, then dividing by two to find the test average.) If the initial velocity is zero, then average velocity is the same as one-half the final velocity. Substitute this in the above equation to get:

$$x = 1/2(v_f)t$$

3. Since the initial velocity is zero, the average acceleration is equal to the final velocity divided by time:

$$a = v_f/t \quad \text{AND} \quad v_f = at$$

4. Substituting this v_f into the above formula gives:

$$x = 1/2(at)t \quad \text{OR} \quad x = 1/2(at^2)$$

5. By algebraically isolating acceleration, the result is:

$$a = 2x/t^2$$

6. With this simple formula, it is possible to calculate the acceleration due to gravity. The height an object is above the floor is "x" and the time it takes for it to fall to the floor is "t".

7. Measure the displacement in meters from the floor to some reference point (the ceiling, safety shower, etc.). Lift the baseball to that height. Use the stopwatch to record the time it takes to fall to the floor. Repeat several times to obtain an average time.

How did your result compare to the accepted value of 9.80 m/s^2?

What are some sources of error?

If the tennis ball was used instead, would the experimental value for acceleration due to gravity be less, more, or the same? Why?

Answer - - The reaction time in starting and stopping the stopwatch is the greatest determinate error. Another source is the height measurement.

Answer - - Acceleration due to gravity is constant for free falling objects. By neglecting air resistance, the acceleration due to gravity is the same no matter what the mass.

NOTE: there is no variable for mass in the formula.

8. Since acceleration due to gravity is known to be 9.80 m/s^2, by measuring the time, the displacement can be calculated:

$$x = 1/2(at^2) = 4.9\text{m/s}^2(t^2)$$

9. Lift the ball a measurable spot above the floor. Record the time it takes to hit the floor and square it. Multiply this number by 4.9 m (the "s^2" units cancel) to determine "x". Now use the meter stick to measure the height. Do the numbers agree?

PROCEDURE III

1. By rearranging the formula in (H) above, it is possible to determine time by measuring the displacement:

$$t^2 = 2x/a$$

2. To find the time it is necessary to take the square root of the quantity (2x/a). In this part, time will be "reaction time".

3. Have a student extend his hand in handshake position. Hold a meter stick so that the zero mark is lined up between the student's thumb and finger. Instruct the student to grip the meter stick as soon as he sees it start to fall. Vertically drop the meter stick between the student's outstretched fingers. Since the initial position was zero, the displacement equals the final position of the thumb and finger in centimeters (x-0=x).

4. The acceleration due to gravity is 9.80 m/s^2. But since you will be measuring in centimeters, the value is 980 cm/s^2. Depending on the class's mathematical abilities, you may want them to calculate their own reaction time based on the above formula or you may choose to tape the following chart on a meter stick for a quick reference. Either way, the students should understand the basis for how the reaction time was determined.

DISTANCE (cm)	REACTION TIME (s)	DISTANCE (cm)	REACTION TIME (s)	DISTANCE (cm)	REACTION TIME (s)
10	.143	20	.202	30	.247
11	.150	21	.207	31	.252
12	.156	22	.212	32	.256
13	.163	23	.217	33	.260
14	.169	24	.221	34	.263
15	.175	25	.226	35	.267
16	.181	26	.230	36	.271
17	.186	27	.235	37	.275
18	.192	28	.239	38	.278
19	.197	29	.243	39	.282

5. Another way to investigate acceleration due to gravity is by dropping a dollar bill through the fingers of a student. To demonstrate this hold a dollar bill so that the middle of the bill is between a student's fingers. If the student doesn't "cheat" and grab before you release the bill, he will not be able to catch it. (Also, it works better to use a new stiff bill, which has less air resistance.)

Can you explain why you can't shut your fingers in time to catch the dollar after it is released?

Answer - - A dollar bill is 15.2 centimeters in length, so the midpoint is 7.51 centimeters. Acceleration due to gravity is 980 cm/s^2. Use the formula: $t^2 = 2x/a$.

$$t^2 = 2(7.51\ \text{cm}) \ / \ (980\ \text{cm/s}^2)$$

$$= 0.0153\ \text{s}^2$$

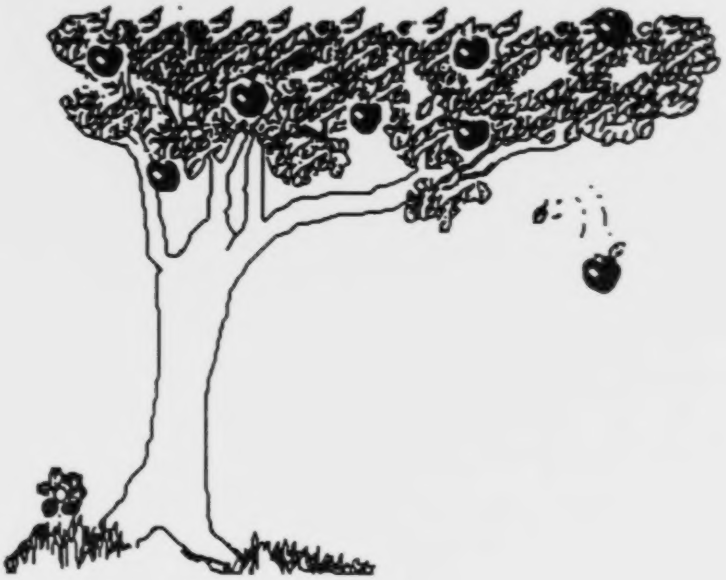
Taking the square root of both sides, the time is 0.124 seconds, which is about one-eighth of a second. The reaction time for the nerve impulses to travel from the eye to the brain and then to the fingers is at least 0.143 seconds (one-seventh of a second).

If a student does catch the dollar, what are some possible explanations?

Answer - - Obviously the student could have anticipated the drop and had a false start. Secondly, the midpoint of the dollar bill might have been above the student's fingers. For example if two-thirds of the dollar bill was above the student's fingers, the time for the bill drop below his fingers is only one-seventh of a second (which is possible for a "reactive student"). Another possibility is the motion of the dollar bill was not free fall (air resistance slowed its fall).

Finally a clever student might have lowered his hand as he/she grabbed for the bill and effectively decreased the relative displacement. This can be avoided by having the student rest their hand on the table top or back of a chair.

TERMINAL VELOCITY: THE FINAL APPROACH
Demonstration



PURPOSE

Neglecting air resistance in free fall motion is nice for doing ideal calculations, but what happens in the "real" world? This little demonstration demonstrates what happens to the motion of falling objects when air resistance cannot be ignored.

MATERIALS

Two sheets of paper (with approximately the same mass)
Light-weight string
A large handkerchief (or bandana)   Two clothespins

PROCEDURE

1. Take the two sheets of paper, wad one up into a ball. Lift the flat sheet and the wadded up sheet the same height above the floor. Drop both at the same time.

Did they both hit the floor at the same time? Explain.

How do you think Aristotle would explain it?

Answer -- Aristotle explained that a feather dropped slower than a rock because the feather was only part solid and part air, while the rock was more like the earth. Since the rock was naturally more like the earth, it had a greater yearning to return to its natural place. Is that true for paper? Obviously not, so what is the justification? The answer is air resistance. Air resistance is the result of a falling object's collision with the molecules of the air. It can be thought of as a fluid friction, a resistance to the downward motion of the object. The collision with air molecules provide an upward force causing the paper to flutter downward.

2. Wad up the flat sheet of paper into a ball as small as possible. If you keep the first ball loosely wadded up and the second one very compacted, the second should hit the floor first.

Does this support Aristotle's view of motion?

Answer -- The two pieces of paper have approximately the same mass, so the earth's gravitational attraction is the same for both. The difference is due to the larger paper wad striking more air molecules as it fell and therefore had more air resistance and was slowed down more.

Which type of paper wad is easier to "shoot" in the waste basket? Why?

Answer -- The compacted paper wad has less interactions with the air molecules and is easier to control when shot through the air at the basket.

3. Use the string to make a parachute out of the handkerchief. Tie the parachute to one of the clothespins. Make sure that you drop the clothespin from a height great enough to allow the parachute to open. (Maybe stand on a table . . .?) Drop the clothespin and clothespin-with-parachute from the same height. Drop the clothespin and clothespin-with-parachute from the same height.

Which do you expect to hit the ground first? Why?

Drop the clothespin and clothespin-with-parachute from the same height.

Did the parachuted clothespin continue accelerating as it fell or did it fall at a steady rate? Explain.

Answer -- The upward force of air resistance depends on the number of molecules in the air that the falling object strikes. When the upward resistance equals the weight of the falling object. The net force and acceleration are zero. The object falls at a constant velocity, called the terminal velocity.

In designing a parachute, how would you decrease the terminal velocity of a falling object?

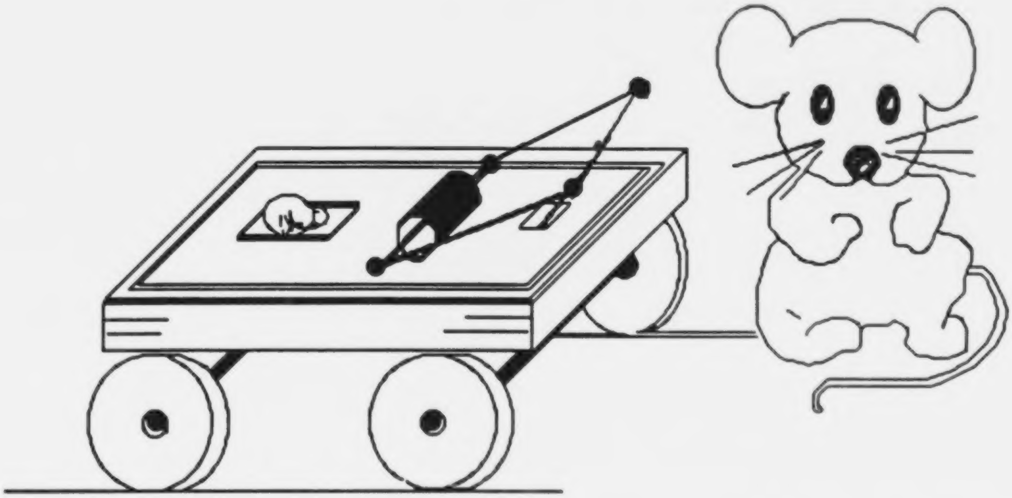
Answer -- A parachute is designed to provide as many collisions with air molecules as possible with a large surface area.

Why can insects fall from tremendous heights, yet walk away unharmed?

Answer -- Insects have large surface areas compared to their small weights. As a result their terminal velocity is very low. This low terminal velocity means they strike the ground with minimal force.

MOUSE TRAP CAR

Laboratory Exercise
--for the teacher--



BACKGROUND

A marble rolled down a plastic ruler or releasing a Hall's carriage down a ramp is commonly used to study motion. By measuring the distance and time, graphs of displacement versus time and velocity versus time can be made.

Besides the concepts listed above, a mouse trap car creates the opportunity to discuss friction, the principle of simple machines such as the lever and wheel and axle, potential energy, Newton's laws, momentum, torque, rotational inertia, and angular acceleration and velocity. And, it involves the students a great deal.

The basic design consists of a string, thread, or rubber band attached to both an axle and the metal U-shaped lever on the trap. The trap is set and the string is wound around the axle. When the trap is sprung, the string is pulled, and the axle is turned which propels the "car" forward. Give the students just enough details on this basic concept and enourage them to be creative with their designs. You can have front-wheel drive or rear-wheel drive, depending if the string is wrapped "under" or "over" the axle. It is even possible to have four-wheel drive. You will be amazed at what students will come up with. Have them consider how to attach the axles to both wheels and to the car body. Friction plays a vital role. The pull cord could be string, rubber band, or maybe something else. Students will need to decide if they want to go for speed or for distance (or both). It is possible for a mouse trap car to displace over 30 meters.

PURPOSE

The purpose of this lab activity is for the student to design and build a mouse trap car. The car is then to be used to study motion in laboratory activity. You may choose to have the students work individually or in small groups. Either way, it is doubtful that they would be able to complete the construction in one lab period, which means that you might decide to have them complete their cars at home. In fact, you may choose to have them do all the designing and construction work as a take-home lab. One of the other purposes of this activity is to have a mouse trap car race. The mouse trap car race provides the opportunity to discuss why some cars go farther and/or faster. (The race naturally provides a little more incentive.)

MATERIALS

Mouse trap
Parts of old toys (particularly axles and wheels
Wood scraps and light pieces of metal
Wooden dowels (for axles)
String, thread, rubber bands, and wire
Metal lids and other disk-shaped objects (for wheels)
Glue, nails, tape, and screws
Ice cream sticks
Pliers, screw drivers, and hammers
Anything else that you think could be used
Hand saws and drills
Prizes: ribbons, certificates, etc.

Ask students to contribute materials that everyone could use to construct the cars (especially with the hand tools), if you construct them in class. It would be helpful if you could get a mouse trap car that someone has constructed to give students an idea of how to make one. Try making a car yourself; it is important that you understand the construction of the mouse trap car so that you can assist the students in their work. The key here is to either build or get a car that has its rear wheels fixed to the axle, i.e., when the axle turns, the wheels must turn. This arrangement will pemit you to use the spring on the mouse trap to turn the axle, which in turn will rotate the rear wheels (you can also power the front wheels if you wish). Place the mouse trap near and above the axle so that when you pull it back, the string or rubber band can be wound around the axle. Thus, when the trap is released, the motion of the cord will spin the axle and the wheel simultaneously--moving the car forward.

If you do not desire to make the car out of wood, plastic cars that are sold in toy stores work well. You can cut them up easily with a hot knife so that you can position the trap above the axle. Merely take an old knife (a butter or carpet knife will do nicely), and heat it up. This knife will cut the plastic like "butter".

PROCEDURE I: building the cars in class

1. Announce to the class at least one week (if not a month) prior to the construction date for students to collect materials to be used for their mouse trap cars. Refer to the materials list on the preceeding page. The ONLY real requirement is that the cars be powered solely by the mouse trap. Besides the materials, encourage them to be thinking about their designs.
2. On the day of construction, centrally locate the materials to provide equal access for each group of students. Demonstrate safety techniques in handling the tools. "Check out" each student before he or she uses any electric tool. Require safety goggles during sawing, drilling, and hammering.
3. Allot ample time for the students to finish their cars at home (at least a couple of days). Then select a day for the big race.

PROCEDURE II: racing the cars

4. On the day of the race, clear a long runway for the distance race. This "race" is concerned with displacement only. You will probably want to allow each car three attempts. (Three or four cars can be raced at the same time).
5. Use the tape to mark a start and finish line one meter apart. This is for the drag race. Race two or three cars at a time until the "fastest" car eliminates all competitors.
6. Arrange for parents and/or teachers with a "free" conference to judge the cars for the most creative design, prettiest, ugliest, etc.
7. Award the winners. Possibilities include: a bag of Cheetos, cheese-flavored kisses, certificate for a cheeseburger, etc.

CONCLUSION

Where was the potential energy of the car stored? What was the potential energy converted to?

Answer -- Potential energy was in the spring mechanism of the trap's lever arm. The potential energy was converted to kinetic energy, mechanical energy, sound, and heat (friction) energy.

Describe the design of the drag race's winning car.

Answer -- It was probably light-weight, had axles that turned freely, and had good traction at the start (so that it did not "spin out").

Did the drag race winner's design differ from the winner of the long distance race?

Answer -- It is common for the same car to win both races. The biggest key here is free turning axles which reduce the friction and allow the car to "coast" farther. A slow, steady pull by the lever arm of the trap will sometimes increase the displacement

How were the axles attached to the car which had the least resistance (turned the easiest)?

Answer -- Metal to metal is usually the best.

Did the mass of the car seem to matter?

Answer -- Since a light-weight car has less inertia, it is easier to start. But once a heavier car is started, it should roll farther (depending on the axle friction)

How did the type of wheel affect the cars?

Answer -- The wheels need to provide enough friction so as not to spin out in the start. The rotational inertia of the wheel will depend on it being solid or rimmed, the radius of the wheel, and the total mass. We recommend rimmed wheels because they have more rotational inertia for the same mass and radius, which means less tendency to slip. The wheel with the greatest inertia will have a lesser rotational inertia for a given torque.

Did any particular pull cord outperform the others?

Answer -- Usually the rubber band provides the smoothest, longest pull. Also the rubber band's friction to the axle is usually superior to string. Of course, the rubber band breaks more frequently.

POSTLABORATORY DISCUSSION

The conclusion questions should provide a source of discussion.

The torque is equal to the product of a force and the lever arm distance. So with the same force (spring on the mouse trap), by increasing the length of the lever arm on the mouse trap, the axle is supplied with a greater torque. Of course you don't get something for nothing. It takes a longer time to pull the extended lever. Even though the car may not accelerate very quickly, it will probably travel farther because the torque acts on the axle longer. Also, the slower pull by the lever reduces the chances of "spinning out" when the lever arm is released at the start.

The axles and axle attachments are crucial. The axles must be firmly attached to the wheels in order to prevent energy loss to slippage. The axles need to turn freely, with the least amount of friction as possible. Wood absorbs air moisture and will swell or "stick". Clean, smooth surfaces such as metal and plastic work better. Plastic axles have a tendency to warp more due to the torque of the lever arm.

Rotational inertia. It is not important that students calculate the rotational inertia of their wheels. It is sufficient for them to realize that rotational inertia (or moment of inertia) depends on the distribution of mass with respect to the axis of rotation. The farther apart the majority of the mass is located, the greater the rotational inertia (the harder it is to start it rotating). Solid cylinder wheels have a rotational inertia equal to:

$1/2\ mR^2$ "m" stands for mass and "R" for the radius

Hollow cylinder wheel's moment of inertia is equal to:

$1/2\ m(R_1^2 + R_2^2)$ R_1 is the radius to the inside of the wheel

R_2 is the radius to the outside rim

You can demonstrate that a solid cylinder has less rotational inertia than a hollow cylinder by rolling one of each down a ramp simultaneously. If both have the same mass of 10 kilograms with the same outside radius of 10 centimeters, but the hollow cylinder has an inside radius of 5 centimeters, then the moments of inertia would be 500 kg-m^2 (solid cylinder) and 625 kg-m^2 (hollow cylinder). The solid cylinder, with less rotational inertia, will start easier and roll down the ramp first.

Hollow cylinder wheels, therefore, are harder to start, but also harder to stop once started. Also it might be interesting to add that the moment of inertia for a solid sphere is:

$(2/5)mR^2$

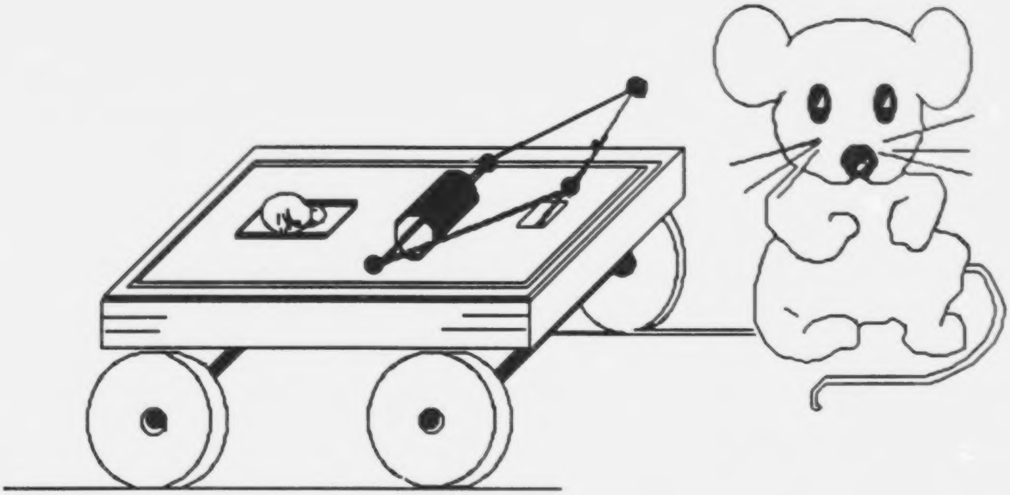
(Of course incorporating solid spheres into the design of the mouse trap car might be a construction problem.)

Since angular acceleration and angular velocity are more difficult concepts to deal with and the math is more involved, they may be inappropriate topics to discuss with physical science students.

MOUSE TRAP CAR

Laboratory Exercise

--for the student--



PURPOSE

The purpose of this lab activity is for you to design and build a mouse trap car. The car is then to be used to study motion in future lab activities. You may have the choice to work individually or in small groups. Either way, it is doubtful that you will be able to complete the construction in one lab period, which means that you might have to complete the cars at home. In fact, you may be assigned to do all the designing and construction work as a take-home lab. One of the other purposes of this activity is to have a mouse trap car race. The mouse trap car race provides the opportunity to discuss why some cars went farther and/or faster.

MATERIALS

Mouse trap
Wood scraps and light pieces of metal
String, thread, rubber bands, and wire
Glue, nails, tape, and screws
Pliers, screw drivers, and hammers
Hand saws and drills
Parts of old toys (particularly axles and wheels)
Wooden dowels (for axles)
Metal lids and other disk-shaped objects (for wheels)
Anything else that you think could be used

All students should help contribute materials that everyone could use (especially with the hand tools).

PROCEDURE I: building the cars in class

1. At least one week (if not a month) prior to the construction date, start collecting materials to be used for the mouse trap cars. (Refer to the materials list.) The ONLY real requirement is that the cars be powered solely by the mouse trap. Besides the materials, you need to be thinking about your design

2. The basic idea is to attach a string or rubber band to the U-shaped lever arm of the mouse trap. The mouse trap is "set" and the free end of the string is wrapped around the axle. When the trap is sprung (or released), the string pulls the axle and propels the car forward.
3. Be careful when using electrical hand tools. Wear safety goggles whenever you are sawing, drilling, or hammering.
4. You will probably need to finish building your car at home.

PROCEDURE II: racing the cars

5. On the day of the race, clear a long runway for the distance race. This "race" is concerned with displacement only. You will probably be allowed three attempts for each car. (Three or four cars can be raced at the same time.)
6. Use the tape to mark a start and finish line one meter apart. This is for the drag race. Race two or three cars at a time until the "fastest" car eliminates all competitors.
7. Parents and/or other teachers will judge the cars for the most creative design, prettiest, ugliest, etc.

CONCLUSION

Where was the potential energy of the car stored? ______________________________

What was the potential energy converted to? ______________________________

____

Describe the design of the drag race's winning car: ______________________________

____

____

Did the drag race winner's design differ from the winner of the long distance race?

____

Explain: ____

____

How were the axles attached to the car which had the least resistance (turned the easiest)?

____

____

Did the mass of the car seem to matter? ______________________________

Explain ____

How did the type of wheel affect the cars? ______________________________

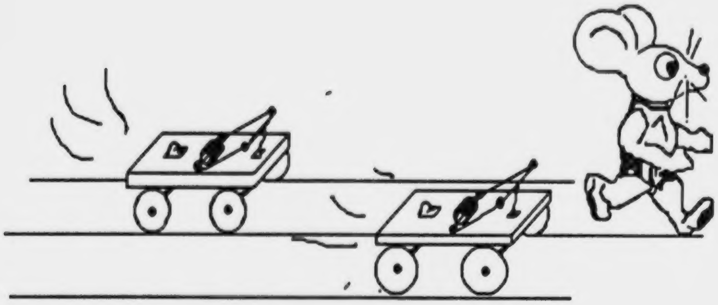
____

Did any particular pull cord outperform the others? ______________________________

____

RATES OF CHANGE AND THE MOUSE TRAP CAR

Laboratory Exercise
--for the teacher--



PRELABORATORY DISCUSSION

Speed and velocity were described in the background information of this unit. Both are concerned with the rate of changing position. Velocity has the added dimension of describing the direction as well speed. The formula to be used is that of velocity, even though, for this lab, the distance and displacement are virtually the same because it is concerned with a linear change of position.

What is the maximum and minimum displacement after one hour if you have an average speed of 55 miles/hour?

Answer - - By traveling in one direction such as north, the maximum displacement would be 55 miles north of the original position. The displacement would be zero if you drove in a loop and ended up where you started. However, the total distance for either journey was 55 miles.

Velocity is the rate of changing position. Rate deals with time. The change in position is displacement. Mathematically, you have $v = x/t$.

Some professional baseball pichers can throw a baseball 98 miles per hour. If the pitcher is about 60 feet from the batter, how long does it take for the ball to reach the batter?

Answer - - Use the factor label method to change mph to feet per second:

(98 mi/hr) (1 hr/3600 sec) (5280 ft/1mi) = 144 ft/sec

$v = x/t$ but since you want to find time:

$t = x/v$ = 60 ft/(144 ft/sec) = 0.42 seconds

Since displacement will be measured in meters and time in seconds, the unit for velocity in this lab will be m/s.

What is the average velocity of a football if it is thrown 25 meters in 2.5 seconds?

Answer - - A displacement of 25 meters in 2.5 seconds is the same as 10 meters displaced in 1.0 seconds or simply 10 m/s.

PURPOSE

This laboratory activity is designed for students to calculate velocity based on data collected from their mouse trap cars. Students can relate to 50 miles per hour, but it is difficult for them to relate to relationsips such as "2.85 m/s" merely by performing mathematical calculations. This activity helps students to correlate what they observer in lab with what they calculate mathematically.

MATERIALS

Mouse trap cars	Meter sticks
Stopwatches	Colored tape

PROCEDURE

1. Clear a runway of approximately six meters (preferably uncarpeted). Use the colored tape to mark the starting line and one meter intervals. It is easier for the timers to see when the car crosses the markings if the tape is one to two meters long (across the width of the runway).

2. Position a timer at each meter interval. Each timer will start timing from the starting line until the car's front end crosses the meter mark he/she is responsible for.

3. Instruct a student to wind up his mouse trap car and place it so the front end is aligned with the starting line. When you announce, "Ready . . . set . . . go" , the car should be released by the student and all of the timers should start timing. (It is generally a good idea to time each car three times to reduce the determinate error).

4. The following is a sample data table similar to that which can be expected to be collected by your students:

Displacement (meters)	Time over entire distance traveled (seconds)	Time over each one meter traveled (seconds)	Average velocity over each one meter traveled (meters per second)
1.0	0.48	0.48	2.08
2.0	0.92	0.44	2.27
3.0	1.33	0.41	2.43
4.0	2.07	0.74	1.35
5.0	3.56	1.49	0.67

a. Time over the entire distance traveled -- this is the stopwatch time at the one, two, three, four, and five meter marks.

b. Time over each one meter traveled -- this is the time it takes the car to tavel between each one meter mark. In order to find the time it took a car to go from the second to the third meter, for example, subtract the stopwatch time at the two meter mark from the three meter mark.

c. Average veloicity over each one meter traveled -- one meter divided by the time it took to travel this distance.

As one can see from the table, the mouse trap car reached its maximun velocity somewhere near the three meter interval and then it began to slow down. Most of the cars students build will reach their maximum velocity at about the one meter mark and then slow down rapidly. At this point you will be tempted to continue on and attempt to calculate acceleration, but this would be a mistake. In order to find the acceleration of the car over a given one-meter interval, you must know the instantaneous velocity at the beginning and at the end of that interval. You do not have that type of information. What you have calculated at this point is the average velocity over each meter traveled. Determining the acceleration is more complicated in this linear motion activity than you may want to get into and you may be conveying an erroneous ideas about this physics concept. Consequently, we recommend that you stop here and be satisfied with the determination of average velocity.

POSTLABORATORY DISCUSSION

Ask several students (or groups of students) to dispaly their data tables on the chalkboard. Check the calculations for accuracy, be sure the students have correctly figured the time it took their car to travel each meter. Use the questions given below in the conclusion section to guide your discussions. This would be a good time to bring up the concept of acceleration but keep it at a descriptive level.

CONCLUSION

1. Over which displacement interval did the car have the greatest speed or velocity?

____

2. Where did the car begin to slow down?

____

3. Does anyone in the class have a car that goes faster and faster over the five meters?

____

4. If there is a car that went faster and faster over the five meters, examine the car and explain why this occurred.

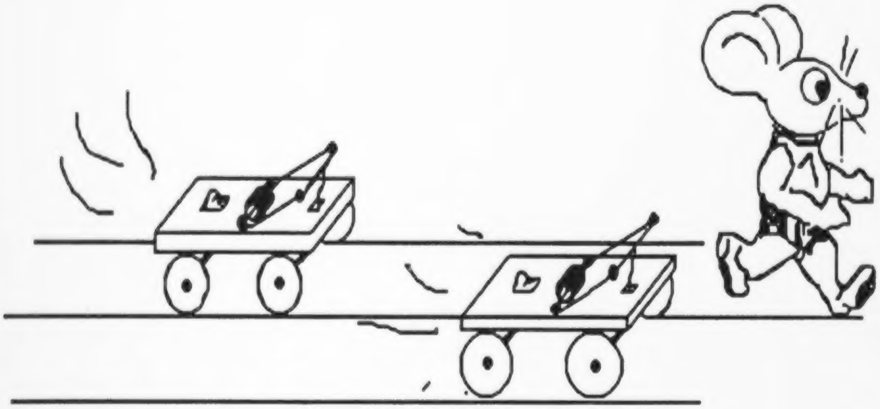
____

____

RATES OF CHANGE AND THE MOUSE TRAP CAR

Laboratory Exercise

--for the student--



PURPOSE

This lab activity is designed to collect data using your mouse trap car. The data will be used to calculate your car's velocity.

MATERIALS

Mouse trap cars	Meter stick
Stopwatches	Colored tape

PROCEDURE

1. Clear a runway of approximately six meters (preferably uncarpeted). Use the colored tape to mark the starting line. Measure one meter from the starting line and tape a line across the runway. This is one meter displacement. Continue taping lines across the runway for each meter of displacement up to five meters.

2. There needs to be a timer at each mark. Each timer will time from the starting line until the car's front end crosses the meter mark that he or she is responsible for.

3. Wind up your mouse trap car and place it so the front end is even with the starting line. You will hear, "Ready . . . set . . . go". On "go" your car should be released and all of the timers should start timimg. (It is generally a good idea to time each car three times to reduce error in starting and stopping the stopwatch. Then average this data and enter it into the table below in the column "Time over entire distance traveled".)

4. Enter your data and calculations in the table given below.

Displacement (meters)	Time over entire distance traveled (seconds)	Time over each one meter traveled (seconds)	Average velocity over each one meter traveled (meters per second)
1.0			
2.0			
3.0			
4.0			
5.0			

a. Time over the entire distance traveled -- this is the stopwatch time at the one, two, three, four, and five meter marks.

b. Time over each one meter traveled -- this is the time it takes the car to travel between each one meter mark. In order to find the time it took a car to go from the second to the third meter, for example, subtract the stopwatch time at the two meter mark from the three meter mark.

c. Average veloicity over each one meter traveled -- one meter divided by the time it took to travel this distance.

CONCLUSION

1. Over which displacement interval did the car have the greatest speed or velocity?

____

2. Where did the car begin to slow down?

____

3. Does anyone in the class have a car that goes faster and faster over the five meters?

____

4. If there is a car that went faster and faster over the five meters, examine the car and explain why this occurred.

____

____

Newton's Laws of Motion

11

Background Information

SIR ISAAC NEWTON

So far motion has been discussed without considering its cause. **Newton's Laws of Motion** are concerned with the forces that affect motion of a body. Galileo adequately detailed laws concerning falling bodies, but it was Sir Isaac Newton who formulated ideas concerning the various kinds of motion due to forces. These concepts are stated in three laws. The first two laws are basically involved with the forces acting on one body. The third law deals with the interaction of two or more bodies.

FIRST LAW OF MOTION

The first law is sometimes referred to as the law of **inertia.** Inertia is related to mass, and like mass, it is constant. The more massive an object, the more inertia it has. Inertia is defined as the tendency of an object to resist any accelerations. For example, a box resting on a tabletop tends to want to remain at rest on the tabletop (unless some outside force acts on it). A marble rolled along the floor at a constant speed tends to remain rolling along the floor (unless some outside force--friction--acts on it). A body with zero velocity has no acceleration, as does a body moving with a constant velocity. Changing the velocity (either by speeding up or by slowing down) results in acceleration, which inertia resists.

SECOND LAW OF MOTION

Since the first law states that a body does not want to change its state of motion, the second law describes the **force needed to overcome inertia.** It is probably not too difficult ot visualize that every large boulder at rest requires a much larger force to get it in motion than that required for a small pebble. Furthermore, once you have this very large boulder rolling down a hill, the force needed to stop it (or even slow it down) is again much larger than that for a small pebble rolling down the same hill. The second law is often reduced to the equation: $F = ma$. F represents the force needed, m is for the mass of the object, and a is acceleration.

THIRD LAW OF MOTION

Newton's Third Law is the most frequently quoted of the three laws. It says that **for every action there is an equal and opposite reaction.** At first this may seem to be contradictory. How can something be equal if it's opposite? But it is necessary to remember that a vector describes magnitude and direction.

If A exerts a 10 newton force to the right on B, then B exerts a 10 newton force to the left on A. A common every day example of this is standing on the ground. The force of your weight pushes down on the earth and the earth pushes back up with an equal force. When the two forces are not balanced, motion results in the direction of the stronger force. For example, if you sit on a cardboard box that does not supply an equal and opposite reaction to the action of your weight, you will go down through the box and accelerate to the floor!

PRACTICING USING NEWTON'S LAWS

Paper and Pencil Exercise

-- for the teacher --

1. A car with a mass of 2000 kg accelerates from rest to 12 m/sec in 4 seconds. How much force was required?

acceleration = change in velocity/time

$a = (12\ \text{m/sec})/4\ \text{sec} = 3\ \text{m/sec}^2$

Force = mass x acceleration

$F = 2000\ \text{kg} \times 3\ \text{m/sec}^2 = 6000$ newtons

The unit of force, the **Newton**, is the amount of force needed to accelerate a one kilogram object one meter per second^2.

2. A rock exerts a force of 2.00 newtons. What is its mass?

acceleration due to gravity (g) equals 9.80 m/sec^2

Force = ma

2.00 newtons = mass x 9.80 m/sec^2

$m = (2.00\ \text{kg-m/sec}^2)/9.80\ \text{m/sec}^2$

m = 0.204 kg OR 204 grams

3. A football is punted with a force of 3500 newtons. If the mass of the football is 7000 grams, what is the acceleration?

7000 grams = 7.000 kg

Force = mass x acceleration

3500 newtons = (7.000 kg) x acceleration

$a = (3500\ \text{kg-m/sec}^2)/7.000\ \text{kg}$

$a = 500.0\ \text{m/sec}^2$

PRACTICING USING NEWTON'S LAWS

Paper and Pencil Exercise
--for the student--

1. A car with a mass of 2000 kg accelerates from rest to 12 m/sec in 4 seconds.
   How much force was required?

The unit for force, the **Newton,** is the amount of force needed to accelerate a one kilogram object one meter per second^2.

2. A rock exerts a force of 2.00 newtons.
   What is its mass?

3. A football is punted with a force of 3500 newtons. If the mass of the football is 7000 grams, what is the acceleration?

NEWTON'S FIRST LAW

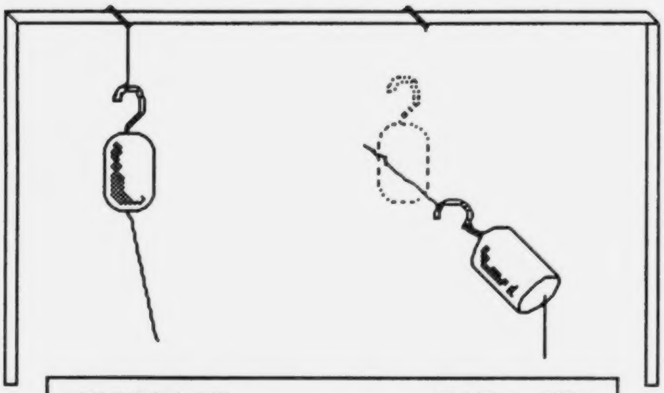
Many Demonstrations

PURPOSE

The purpose of the following demonstrations is to allow the students to see inertia in action. First hand observation will give the students a better understanding of inertia.

MATERIALS

- Thread
- 1 kilogram weight
- Part of an old sheet
- Spoon, plate, glass
- Heavy weight or rock
- Hammer and nails
- Thin board
- Butcher knife
- 10-pennies
- Beaker
- 3x5 card
- Apple
- Toilet paper core
- Pie plate
- Egg

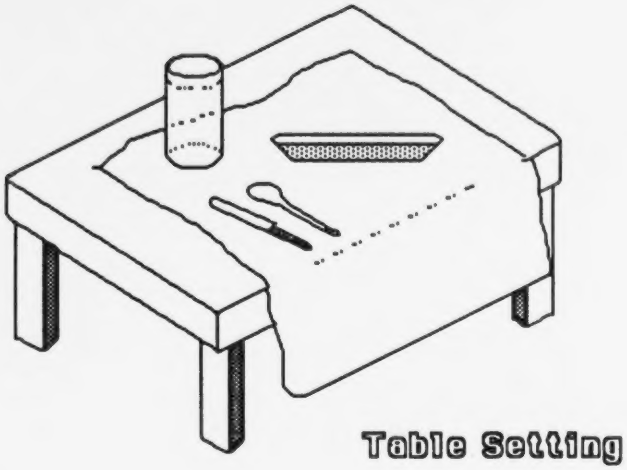


"YANK IT -------- PULL IT"

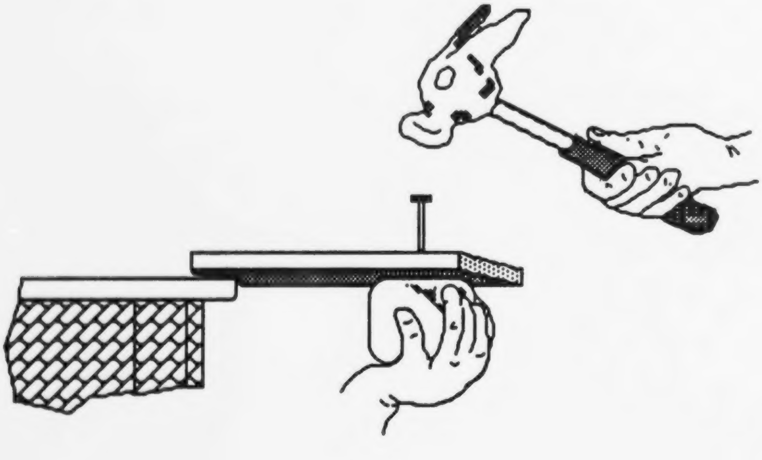
PROCEDURES

1. Tie the thread to the top and bottom of the kilogram weight. Suspend the weight above a table top. There should now be a thread attached from the support to the top of the weight and a thread hanging from the bottom of the weight. Give a quick jerk to the bottom thread. The tension in the bottom thread will increase. The difference between the tensions in the threads is equal to the product of the mass of the kilogram weight times the acceleration minus the weight (mg). If the mass time the acceleration is greater than mg, the tension in the upper thread will be less and the bottom string breaks. The top thread experiences less tension than the bottom thread because the kilogram weight serves to diminish the doward force due to its interia.

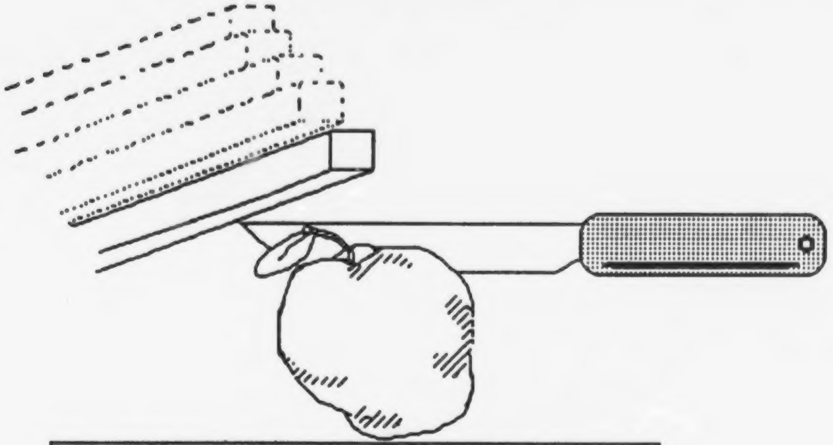
Now tie another piece of thread to the bottom of the weight and pull with a slow, steady force. The top thread will now break and the weight will come crashing down. BE CAREFUL not to let it land on your foot! The students should explain that since the force applied was small enough to make the acceleration small. The tension in the upper thread was greater than the tension in the lower thread and the thread broke at the top. The combination of the force of the weight in motion downward and the downword force from the hand causes the thread to break above the weight.



2. Cut an old sheet approximately 18 inches by 24 inches. Make sure that there is no hem left on any side. Lay the sheet on a smooth table so that about six to eight inches hangs over the edge. Place the table setting (spoon, glass, and plate) on the "table cloth". Grab both sides of the sheet and, with a quick downward jerk, snap the cloth out from underneath the place setting. Due to inertia you can slide the sheet out from beneath the place setting.

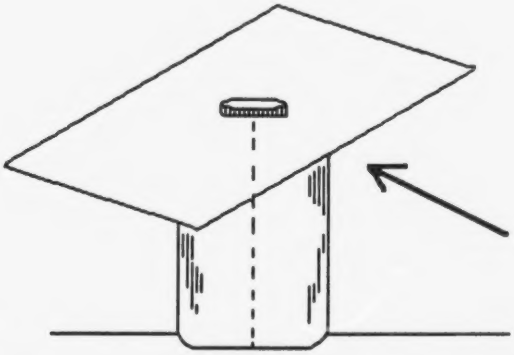


3. Extend a thin board past the edge of a table. Brace the end of the board that is on the table (possibly have a student stand on it). Use the hammer to try to drive a nail into the end of the board hanging over the edge of the table. Next have another student hold a heavy weight under the unsupported end and attempt to drive the nail again. It is easier the second time due to the inertia of the heavy weight.



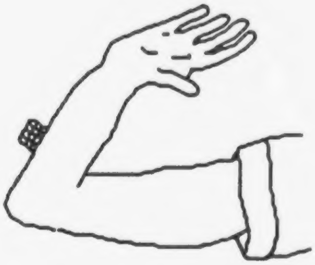
"Cutting an apple in mid-air."

4. Take the butcher knife and push the blade just far enough into the apple so that the apple stays on the blade of the knife when the knife is picked up. Use your hand, a hammer, or a mallet to give the blunt edge of the knife a sharp whack. The knife will pass through the apple. The apple will be cut in half due to its inertia.



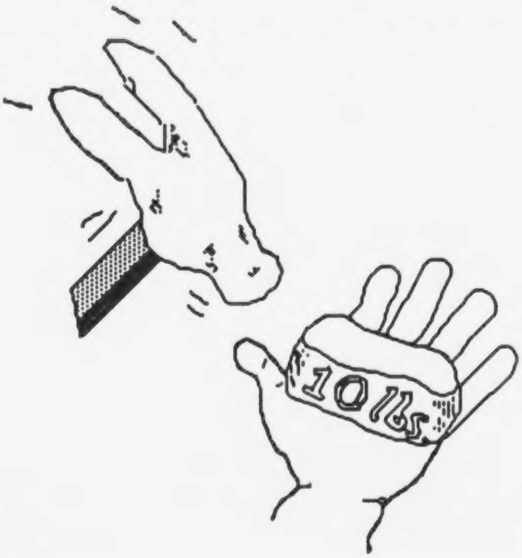
3x5 card and coin

5. Use the glass from the table setting demonstration. Place the 3x5 card over the mouth of the glass. Set a piece of chalk, a marble, or a penny on the card. "Flick" the card. With practice, you can knock the card out from beneath the penny and it will drop into the glass. This is the same principle as the table setting.

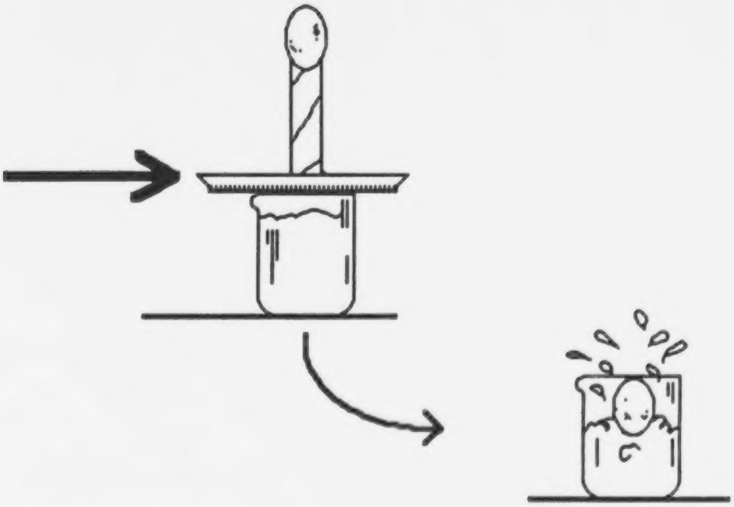


Falling Pennies

6. Bend your arm so that your hand is near the back of your head. Place a penny on the flat part of your forearm near your elbow. Quickly jerk your elbow down and catch the penny in the palm of your hand. See how many pennies you can stack on your arm and still be able to catch them.



7. Lay your hand (palm up) on a table top. Place a heavy weight (10 pounds) on the palm of your hand. Strike the weight with the hammer. Your hand will not feel the impact of the hammer due to the inertia of the weight.



8. Fill a beaker about two-thirds full of water. Set the pie plate on the mouth of the beaker. Stand the toilet paper core on the pie plate so that it is directly above the beaker of water. Set the egg on the open end of the toilet paper core. Hit the pie plate with a sharp horizontal force. The egg will drop into the beaker of water.

STUDYING NEWTON'S LAWS OF MOTION

Laboratory Exercise

--for the teacher--

PURPOSE

The purpose of this lab activity is to use the mouse trap car to study Newton's second law of motion. Hall's carriages will also be used to study the first law.

MATERIALS

Hall's carriages
Mouse trap car from previous lab
Clothes pins
Stop watches
Meter stick
Spring scales

PRELABORATORY DISCUSSION

In order to study the effect of a force on a body it is necessary to review the concept of acceleration. Acceleration is basically how much the velocity of an object changes in a certain amount of time. It is sometimes determined by taking the difference between two velocities at two points in time and dividing by the difference in the time.

What are the units for acceleration?

Answer - - meters per square second (m/sec^2)

What is the acceleration of an object if it takes 10 seconds to increase its velocity by 40 m/sec?

Answer - - acceleration = change in velocity/time
$a = (40\text{m/sec})/10\text{ sec} = 4\text{ m/sec}^2$

It may be necessary to review how velocity is determined. The average velocity is found by dividing the total distance by the total time. This is important because for this lab the velocity must be calculated first to determine the acceleration.

What is the average velocity of someone who runs the 100 meter dash in 10.7 seconds

Answer - - velocity = distance/time
$v = 100\text{ m}/10.7\text{ sec} = 9.35\text{ m/sec}$

If someone could run at that constant velocity for 1500 meters (0.93 miles), how long would it take?

Answer - - velocity = distance/time
time = distance/velocity
$t = 1500\text{ m}/(9.35\text{ m/sec}) = 160.4\text{ sec}$ OR 2 min. and 40 sec!
(The world record is about 3.5 minutes.)

It is necessary to differentiate between weight and mass. Mass is a constant, independent of gravity. Mass is a measure of the quantity of matter contained in something. Weight is a force and is dependent upon the gravitational attraction for an object. Weight is basically a substitution of Newton's Second Law. This law is given by the formula: $F = ma$. (See background discussion.) Weight equals the mass times the acceleration due to gravity.

How would you determine the mass of a 5 newton rock?

Answer - - Since weight = mass x acceleration,
mass = weight divided by acceleration.
($m = 5 \text{ N}/9.80 \text{ m/sec}^2 = 0.510$ kg or 510 grams)

What units make up a newton?

Answer - - kilogram-meter/second^2

Since the moon's gravitational attraction is 1/6 that of the earth's, what would be the mass of the rock (in question 5) on the moon?

Answer - - The mass is constant. Therefore the rock's mass on the moon would be the same as on the earth (510 grams).

What would be the weight of the rock on the moon?

Answer - - The weight would be 1/6 of 5 N, or 0.833 N.

PROCEDURE I: FIRST LAW

1. Stand a clothes pin up inside a Hall's carriage. Quickly jerk the Hall's carriage forward.

What happened to the clothes pin? Explain.

Answer - - The clothes pin fell backward. This is because of inertia. The clothes pin was at rest and had a tendency to remain at rest. It resisted the forward motion which would have caused acceleration.

2. Again stand the clothes pin in the carriage. This time give a gentle pull to the carriage and then stop it suddenly.

Explain your observations this time.

Answer - - The clothes pin did not fall until it was stopped because the initial acceleration was very slight. The force needed to cause the acceleration was small enough not to disrupt the inertia of the clothes pin. When the carriage was stopped suddenly, the pin fell forward because of inertia. Now that it was moving at a constant velocity, it tended to remain in motion.

Why was the Hall's carriage used for this part?

Answer - - It has very little friction.

PROCEDURE II: SECOND LAW

3. Using the spring scales, determine the weight of your mouse trap car to the nearest tenth of a newton.

4. Calculate the mass of your car in kilograms.
(Weight = mass x 9.80 m/sec^2

5. Measure a distance of 2.0 meters on a tiled floor. Record the time it takes for the mouse trap car to travel the 2.0 meter distance.

6. Calculate the velocity for the 2.0 meter drag strip. ($v = d/t$)

7. Determine the acceleration by taking your velocity and dividing by the time again. ($a = v/t$)

Since you know the mass of the car and have now calculated its acceleration, how large of a force would you have to have in order to completely stop the car? (Assume the negative acceleration or deceleration is equal to the acceleration.)

Answer - - Answers will vary, but the force will be equal to the mass x acceleration.
Note: The force will be negative due to the negative acceleration. This is because the force must be in the direction opposite the motion of the car.

Based on your answer in the question above, would the car hit the wall with a force greater than its weight?

Answer - - If the car was able to travel the 2.0 meters in 0.45 seconds or less, the acceleration would be equal to or exceed the acceleration due to gravity. Since the mass is constant, if the car was able to accelerate faster than 9.80 m/sec^2, then it would hit the wall with a greater force than its weight.

If the car did hit the wall with a force greater than its weight, where did the extra force come from?

Answer - - The potential energy of the coiled spring provides the mouse trap with the extra force.

CONCLUSION

From this lab the students should conclude that a force is needed to change the motion of an object with constant velocity. Constant velocity means zero acceleration. For an object at rest, a force is required to put the object in motion because an acceleration takes place. Once in motion, an object tends to remain moving without accelerating unless some outside force acts upon it. Newton's first law of inertia describes objects with no acceleration and no external forces. His second law relates acceleration to some external force. Both laws are used to explain the motion of objects.

POST LABORATORY DISCUSSION

What would happen to the acceleration of your mouse trap car if you were to double the force of the spring?

Answer - - Since force and acceleration are directly related, by doubling the force, the acceleration would also double.

If the force was held constant, how would you triple the acceleration?

Answer - - If the force is constant the only two variables are acceleration and mass, which are inversely proportional, so in order to triple the acceleration, the mass must be cut to one third.

When would the force be the greatest?

Answer - - At the time of maximum acceleration (probably within the first meter of the drag strip).

Once the car is released the acceleration increases then decreases until the car comes to rest. Explain.

Answer - - The potential energy of the spring is converted into kinetic energy, causing acceleration. After the mouse trap lever no longer pulls on the axle, the effect of friction is observed. Eventually, friction completely negates the force input and the car stops.

As calculated in question 2, the acceleration is inversely proportional to the mass. Could you reduce the mass TOO much to win a one-meter drag race?

Answer - - Yes. If the mass is too small, the weight may be too small to provide enough friction between the car and the floor. The result would be the car spinning its wheel wildly, but not going anywhere.

STUDYING NEWTON'S LAWS OF MOTION

Laboratory Exercise

--for the student--

PURPOSE

The purpose of this lab activity is to use the mouse trap car to study Newton's second law of motion. Hall's carriages will also be used to study the first law.

MATERIALS

Hall's carriages
Mouse trap car from previous labs
Clothes pins
Stop watches
Meter stick
Spring scales

PROCEDURE I: FIRST LAW

1. Stand a clothes pin up inside a Hall's carriage. Quickly jerk the Hall's carriage forward.

   What happened to the clothes pin? Explain!

2. Again stand the clothes pin in the carriage. This time give a gentle pull to the carriage and then stop it suddenly.

   Explain your observations this time.

   Why was the Hall's carriage used for this part?

PROCEDURE II: SECOND LAW

3. Using the spring scales, determine the weight of your mouse trap car to the nearest tenth of a newton.

4. Calculate the mass of your car in kilograms.
   (Weight = mass x 9.80 m/sec^{2})

5. Measure a distance of 2.0 meters on a tiled floor. Record the time it takes for the mouse trap car to travel the 2.0 meter distance.

6. Calculate the velocity for the 2.0 meter drag strip. (v = d/t)

7. Determine the acceleration by taking your velocity and dividing by the time again. (a = v/t)

Since you know the mass of the car and have now calculated its acceleration, how large of a force would be needed to completely stop the car?

____

____

Based on your answer in question 3, would the car hit the wall with a force greater than its weight?

____

____

If the car did hit the wall with a force greater than its weight, where did the extra force come from?

____

____

CONCLUSION

Write a paragraph of your observations made during this lab. Be sure to describe Newton's first and second laws of motion as they related to this activity.

____

____

____

Friction

Background Information

12

DEFINITION

1a: the rubbing of one body against another;
1b: resistance to relative motion between two bodies in contact.

The irregular surfaces on objects "catch" and snag as they are forced to slide past each other. Obviously the more irregular the surfaces, the greater the opportunity to get caught. But even objects that are highly polished have microscopic irregularities. There may also be intermolecular forces of attraction between the molecules of the two surfaces (e.g. electromagnetic forces). The combination of all forces that resist motion is called **friction.**

The friction force is parallel to the surfaces that are in contact and in the direction opposite to the force producing the motion.

Friction is directly proportional to the force pressing the two surfaces together. For example, the force of friction in sliding an empty stool across the floor is slight. The friction is greatly increased when a person sits on the stool. The stool tends to "dig in" to the floor, causing more points of contact AND more pressure. However, for two objects of the **same weight,** the force of friction does not vary much with the area of contact. By increasing the area, the pressure (weight per unit area) is decreased. As a result, the area and pressure tend to cancel each other's affect.

EFFECTS OF FRICTION

Friction is not always bad. Without friction we would not be able to walk because our feet could not "grip" the ground. Not only could we not push ourselves forward, sideways, or backwards, but we wouldn't even be able to stand up on a purely frictionless surface. Except for air hockey, all sports are heavily dependent of friction. Running, jumping, throwing, catching, and hitting would be impossible without friction taking place. Automobiles couldn't start, stop, or turn. Friction is increased in the winter by adding sand to icy streets and sidewalks. Rosin and tar are used by atheletes to increase the friction. Recently, George Brett of the Kansas City Royals had a home run disallowed for exceeding the limit of pine tar on his baseball bat. (He later won his appeal and the home run was allowed.)

Sometimes friction can be a nuisance. Shoes, tires, belts, and ball bearings wear out due to friction. Trying to move heavy objects is made more difficult because of friction. Since friction is in the negative direction of the force producing a motion, the work put into a system is always greater than the work output. (Work is the product of the force and the distance a body moves **in the direction** of the force.) The more friction, the less efficient the machine is. Efficiency is the ratio of the work output to the work input. Most of the work or energy "lost" due to friction results in heat energy.

Lubricants are often used to reduce friction. The friction between a thin layer of oil and a solid is usually less than between two solids. Water slides such as WaterWorld and Schlitterbaun use water to reduce the friction between the slide and the person sliding. Teflon is a coating which has very little friction. Jets that fly at very high speeds are sprayed with teflon to cut down air friction. Ball bearings are used because rolling friction is less than sliding friction. It should also be noted that the force of friction to start something sliding is greater than the force of friction to keep it sliding. This is compared in the following table:

COEFFICIENTS OF FRICTION*

SURFACES	STARTING FRICTION	SLIDING FRICTION
steel on steel	0.74	0.57
glass on glass	0.94	0.40
wood on wood	0.50	0.30
teflon on teflon	0.04	0.04
rubber tire on a dry road	--	0.70
rubber tire on wet road	--	0.50

*The coefficient of friction is the ratio of the force needed to overcome friction to the weight of the object to be moved.

Example:

A wood block weighs 10.0 Newtons. A force of 2.0 Newtons is needed to start the block sliding over a glass table top. The coefficient of friction would be equal to 0.20.

INVESTIGATING FRICTIONAL FORCES

Laboratory Exercise
-- for the teacher --

PURPOSE

The purpose of this laboratory exercise is to compare starting, sliding, and rolling frictional forces. The students will have the opportunity to compare various surface interactions, such as smooth, rough, and lubricated. Friction will also be compared to weight and the surface area.

MATERIALS

String
Spring scales
2" x 4" wooden block
Sandpaper
Round pencils or dowel rods
Metal strips (copper, zinc, or aluminum)
Styrofoam (panels)
Small weights
Glue
Hammer
Wood plank or shelf
Small nails or hooks
Hard plastic strips

Most of the above materials are to be used to make a dragging sled to observe various surface interactions. Basically, the 2"x4" can have a different surface glued to it.

PRE-LABORATORY DISCUSSION

Is friction a positive or negative phenonema?

Answer - - Without friction, motion would not exist as we now know it (see background). However, friction requires more effort (work input) due to the energy "lost" to heat. The energy is not really lost (conservation of energy) but is transformed from mechanical to heat energy.

Friction makes it possible to move around by allowing us to push ourselves forward. If we were in a truly frictionless environment, how could we transport ourselves?

Answer - - Newton's third law says that for every action there is an equal (in magnitude) and opposite (in direction) reaction. This is the principle behind rockets where gases are forced out the rear causing the rocket to shoot forward.

What type of surface interactions would you expect to have the highest frictional force? The least?

Answer - - Rough surfaces provide a greater opportunity for the surfaces to "snag". Smooth surfaces should provide less resistance. Lubricated surfaces are less affected by friction.

Why is oil added to a car's engine?

Answer - - To lubricate the moving parts. Reduced friction means less wear, less work input needed, less energy transformed to heat.

What are some examples of lubrication?

Answer - - Oil (engines), grease (wheels and axles), ball bearings (motors and wheels), teflon (pots and pans), water (slides).

PROCEDURE I (building the sliding block)

1. Glue sandpaper to one broad side and one narrow side of the 2" x 4". This will allow you to compare friction to the two surface areas.
2. Glue the metal strip to the other narrow side. The fourth side of the block can be left as wood. If a panel of styrofoam is available, you might choose to glue the styrofoam to the last side.
3. Screw in a hook to either end of the wood block. You can also hammer a nail part way into the block and then bend the nail to form a hook. The hook will be used to attach the pulling string.
4. Allow the glue to set. Make sure that the edges are sealed well.

PROCEDURE II (collecting data)

1. Lay the wide, sandpapered-side of the block on a smooth counter top, wooden plank, or tiled floor. Attach one end of the string to the block and the other to the spring scale. Pulling very slowly, carefully observe the force needed to start the block in motion. Record three readings and take an average.
2. Use the same side of the block and the same surface. Record three observations of the force required to keep the block moving AFTER it is once started.

Which was greater, the starting or sliding friction?

Answer - - Starting friction is greater (due to inertia).

Describe the motion of the block immediately after it started to move. Explain.

Answer - - The block jerked forward. The force to overcome the starting friction is greater than the sliding friction force. Once the block starts to move, it has a greater force acting on it than it needs and it jumps forward (accelerates momentarily).

3. Now use the narrow sandpapered-side of the block and repeat steps 1 and 2. (Again, take three readings and find the average).

How did your results in step 3 compare with 1 and 2?

Answer - - The data collectes should be very similar.

What does this suggest about the area in contact and friction?

Answer -- When the weight is the same, friction is independent of the area of contact (pressure and area cancel each other).

4. Once again using the wide, sandpapered-side, add some small weights to the top of the block. Repeat steps 1 and 2.

In which case was the friction the greatest? Explain.

Answer - - Friction is greatest when the pressure between the surfaces in contact is the highest. This is because friction is directly related to the perpendicular forces between the surfaces.

5. Place round pencils or dowel rods beneath the block. Find the average starting and sliding friction (steps 1 and 2).

Explain the data observed in step 5.

Answer - - Starting and sliding friction with rollers is very nearly the same value. Also , rolling friction is less than both starting and sliding frictions. The rollers act as a lubricant.

6. Use the wooden block to compare as many surface interactions as possible.

wood-wood
wood-styrofoam
metal-metal
metal-styrofoam
plastic-wood
plastic-glass
plastic-tile

wood-carpet
wood-glass
metal-carpet
metal-glass
plastic-metal
plastic-plastic
styrofoam-styrofoam

wood-tile
wood-sandpaper
metal-tile
metal-sandpaper
plastic-carpet
plastic-styrofoam

CONCLUSIONS

The force needed to start an object sliding is greater than the force needed to keep it sliding. Rolling friction requires less force than starting or sliding friction. This is the principle behind lubrication.

POST-LABORATORY DISCUSSION

1. Describe some ways that friction is beneficial.

Answer - - Friction helps in starting, changing direction, and stopping.

2. In what ways is friction a detriment or problem?

Answer - - Friction requires more force to start objects in motion and to keep them in motion.

3. It is necessary for you to design a system that will allow two obejcts to slide past each other. However, the objects are not enclosed. This means the lubricant cannot be a liquid. What would you do?

Answer - - There are at least two options. One can use a solid coating that has a very low coefficient of friction (such as teflon). Depending on the unit, it might be possible to use ball bearings or some other type of rolling part. A third possible option would be to use a metal that is nearly self-lubricating, such as an alloy of lead and antimony.

4. What do oil, grease, teflon, and plastic have in common as lubricants?

Answer - - They are all organic compounds. They are basically unaffected by electromagnetic interactions which increase friction.

INVESTIGATING FRICTIONAL FORCES

Laboratory Exercise

--for the student--

PURPOSE

The purpose of this laboratory exercise is to compare starting, sliding, and rolling frictional forces. You will be provided the opportunity to compare various surface interactions, such as smooth, rough, and lubricated. Friction will also be compared to weight and the surface area.

MATERIALS

String
Spring Scales
2" x 4" wooden block
Sandpaper
Round pencils or dowel rods
Metal strips (copper, zinc, or aluminum)
Styrofoam (panels)
Small weights
Glue
Hammer
Wood plank or shelf
Small nails or hooks
Hard plastic strips

PROCEDURE I (building the sliding block)

1. Glue sandpaper to one broad side and one narrow side of the 2" x 4". This will allow you to compare friction to the two surface areas.

2. Glue the metal strip to the other narrow side. The fourth side of the block can be left as wood. If a panel of styrofoam is available, you might choose to glue the styrofoam to the last side.

3. Screw in a hook to either end of the wood block. You can also hammer a nail part way into the block and then bend the nail to form a hook. The hook will be used to attach the pulling string.

4. Allow the glue to set. Make sure that the edges are sealed well.

PROCEDURE II (collecting data)

1. Lay the wide, sandpapered-side of the block on a smooth counter top, wooden plank, or tiled floor. Attach one end of the string to the block and the other to the spring scale. Pulling very slowly, carefully observe the force needed to start the block in motion. Record three readings and take an average.

2. Use the same side of the block and the same surface. Record three observations of the force required to keep the book moving AFTER it is once started.

Which was greater, the starting or sliding friction?

____

____

Describe motion of the block immediately after it started to move. Explain.

3. Now use the narrow, sandpapered-side of the block and repeat steps 1 and 2. (Again, take three readings and find the average).

   How did your results in step 3 compare with 1 and 2?

   What does this suggest about the area in contact and friction?

4. Once again using the wide, sandpapered-side, add some small weights to the top of the block. Repeat steps 1 and 2.

   In which case was the friction the greatest? Explain.

5. Place round pencils or dowel rods beneath the block. Finid the average starting and sliding friction (steps 1 and 2).

   Explain the data observed in step 5.

6. Use the wooden block to comapre as many surface interactions as possible:

   wood-wood
   wood-styrofoam
   metal-metal
   metal-styrofoam
   plastic-wood
   plastic-glass
   plastic-tile
   wood-carpet
   wood-glass
   metal-carpet
   metal-glass
   plastic-metal
   plastic-plasatic
   styrofoam-styrofoam
   wood-tile
   wood-sandpaper
   metal-tile
   metal-sandpaper
   plastic-carpet
   plastic-styrofoam

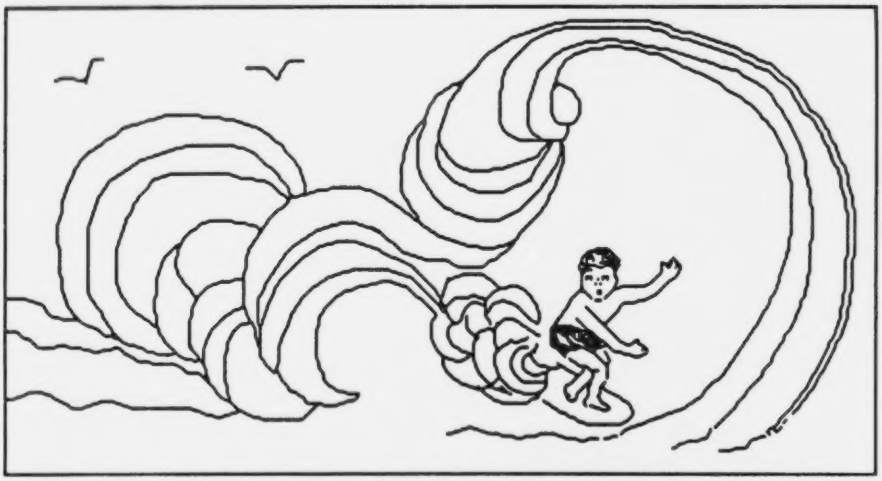
CONCLUSIONS

Write a summary paragraph covering what this lab activity demonstrates concerning friction. Compare starting, sliding, and rolling frictions. Include which surface interactions had the least and the most friction.

Waves and Light

Background Information

13



Ocean waves represent one form of periodic motion.

Few natural phenomena provide the fascination generated by the observation of waves. Who, provided with stones and a suitable pond or puddle, can resist the temptation to skip a stone across the surface and watch the disturbances gently undulate, interact to form patterns, and slowly fade away? Small children make waves in the bath, watch them in awe, and become frustrated in their attempts to catch them. Artists, writers, poets, and scientists have shared this fascination and frustration in their attempts to capture in verse, in story, in color, and in scientific description that something which moves and disturbs but which does not transform the medium itself.

Physical science students are not immune to this fascination. However, in the transition from casual observer to students of the phenomenon, they must actively participate in generating and describing the motions of the waves. The primary task of a physical science teacher is to develop strategies which will involve students in this study in a meaningful and constructive way. Involvement is the easy part -- the catch is to have students gain meaning from the study.

Water waves represent only one of several forms which periodic motion can take. Two other familiar wave phenomena are light and sound.

The notion that sound is related to vibration and to waves has been recognized for many centuries. As early as 500 B.C., philosophers speculated on the nature of sound and how it was produced. Pythagoras studied the sounds produced by the monochord (a one-stringed musical instrument) to experiment with the relations between frequency, length, and tension. The phenomena of reverberation, echo, and interference had all been described well before the end of the first century A.D. and the application of these ideas is evident to those who visit churches which were constructed in medieval times. By the sixth century A.D., sound waves were likened to a series of waves which are propagated in all directions in the air, much as waves are propagated on the surface of water in two dimensions.

In the seventeenth century, Galileo determined the laws which governed the relationships between the physical properties of vibrating strings and frequency. In that same century, Robert Boyle was able to demonstrate that sound waves do not travel in a vacuum. Newton investigated the speed of sound in air, and by the eighteenth century LaPlace had accounted for the variations in the velocity of sound by considering temperature effects.

While it was generally accepted that sound is produced by vibrating bodies, the study of light has often been a subject of controversy. Many, including Plato and much later, Newton, explained the behavior of light in terms of corpuscles or particles. Aristotle, although not proposing a wave theory, insisted that light could not be particulate because it was inconsistent with his theory that all of space was filled with very finely divided matter. Roger Bacon and Robert Hooke, seventeenth century contemporaries of Newton, favored a wave theory of light.

Christian Huygens, another contemporary of Newton, attempted to explain the behavior of light in terms of wave motion. Although he was successful in accounting for the observable phenomena, the controversy surrounding the nature of light continued. It was not until early in the nineteenth century when Thomas Young's experiments with water waves provided enough evidence to support the wave theory that the wave nature of light became popular.

But the nature of light was not to be so easily explained. With the introduction of Einstein's equations early in the twentieth century, scientists were again confronted with reconciling the characteristics of light which were at once both particulate and wave in nature. While experiments with interference and diffraction appeared to show that light travels as a wave, the study of photoelectric emission and absorption were equally as convincing in showing that light had a particle nature. The resolution of these conflicting phenomena ushered in the era of modern physics. Today, scientists generally agree that light travels as electromagnetic waves and that the absorption and emission of light involves the acceleration of a particle.

MECHANICAL WAVES
Demonstration

PURPOSE

The purpose of this demonstration is to introduce the basic terminology and concepts of wave motion. The best way to **introduce** the concepts of wavelength, frequency, amplitude, crest, trough, node, and antinode is through the use of the long coiled spring. If you do not have a spring, a suitable substitute is rope or length of rubber tubing.

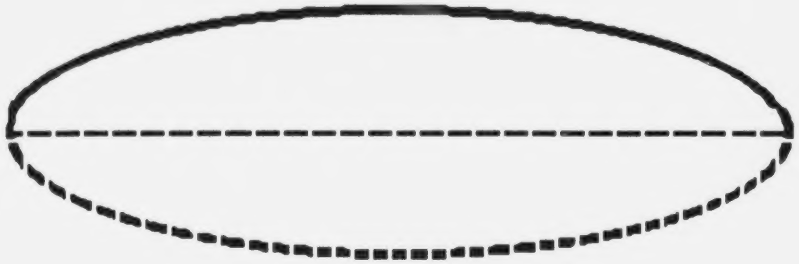
MATERIALS

Long coiled spring or suitable substitute (15 foot length of rope or rubber tubing) and Transparency Set 1 shown on page 5.

PROCEDURE

1. Have a student hold one end of the slightly stretched spring and you hold the other end. (If a rope or length of rubber tubing is used, you will need to leave some slack in it so that there will be some room for motion.) Be sure to instruct the student to hold his/her hand as still as possible and to hold on tightly. If the student's hand moves, you may get interference in the waves - something we are not ready for just yet. On the other hand, it is very difficult to maintain dignity and decorum if the student releases the spring and you end up with the spring encircling you.

   Rule 1: Trust the kid who holds the other end of the coiled spring or prepare a lecture/demonstration on how mummies are wrapped.



FUNDAMENTAL (First Harmonic)

2. Move your hand up-and-down so that the spring vibrates in one part -- that is -- the whole spring moves up and then moves as a whole down. This is the **Fundamental** and the **Wavelength** is the distance from your hand to the student's hand and back. Be sure to emphasize that the **Wavelength** (λ)is the distance "over and back" and that this is the

equivalent of a **Fundamental** wave which you will study about when you get to sound. During the time that the waves are being produced, dwell on the definitions and repeat the definitions as you increase the frequency of the waves. Keep in mind that the words used to describe wave motion may be familiar to your students but the context in which the words are being used may be new to them. Repeat the words often, apply the definitions, and have the students use and repeat the words and the definitions.

3. The illustration on the previous page shows the fundamental vibrating in one segment, one up and one down over the length of the wave. This is the first harmonic. Transparency set 1 on the following page shows the second harmonic with the wave vibrating in two segments and vibrating in three and four segments (the third and fourth harmonics) respectively. Students are likely to suffer from an information overload if they are not shown the actual waves with the spring or rope. Go over the definitions while using the spring to demonstrate the ideas.
   The fundamental (first harmonic) exists when the spring vibrates as a whole -- only one up and one down over the length of the spring. The second harmonic is a vibration of the spring in two segments, the third harmonic vibrates in three parts, i.e., three ups and three downs over the length of the spring. It may also be useful to point out that the first overtone is the second harmonic, the second overtone is the third harmonic, etc., as you cover these concepts. This will help you and the students when you work on sound.

4. Students should count the number of waves and the number of segments in the vibrating spring. Hopefully, they will find that it is impossible to get standing waves in fractional parts. The concept of node can be demonstrated by tieing a handkerchief loosely around the spring. As the spring vibrates in a standing wave, the handkerchief will move to a node where it will have minimum movement. A good demonstration is to have a student hold on to the handkerchief while the spring is moving. With a little practice, the student can hold the spring loosely at a node with his/her hand and the spring will continue to move up and down. If the handkerchief (or hand) is moved to any position other than the node, interference will result and the wave will deteriorate.

LAW 1: Every student in the class will actively participate in learning. The pain in the back of the row is a prime candidate to make waves. Let that student wave the spring while you move about the class asking questions. For example:

Name the highest point on the wave (Antinode); **another name** (Crest); **the point which does not move, or moves very little,** (Node); **the points held by the students** (Nodes); **the name for vibration in one part** (Fundamental); **another name** (First Harmonic)

What is the relationship between the speed at which the hand moves up and down (vibrates) and the number of segments produced? (The faster the vibration, the greater the number of segments produced and the greater the **Frequency. What is the symbol for frequency?** (f).

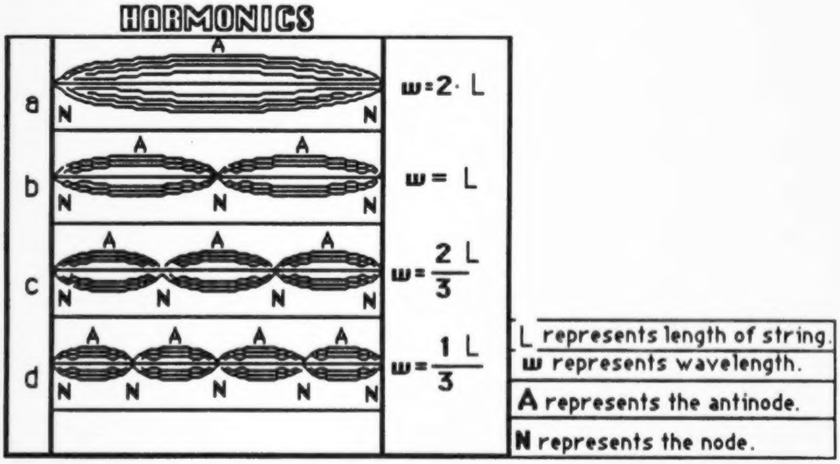
What is the relationship between the distance the hand moves up and down and the amplitude of the wave? For a given frequency, the greater the motion, the greater the energy input, and the greater the amplitude. (Note that there is a difference in the amount of energy required to produce a wave and the amount of energy required to produce many waves.) If your rubber duck were to fall into the bathtub a small wave of small amplitude would result. If you were to jump into the bathtub it would make a big wave of large amplitude.

Is it possible to produce one half of a wave?

Answer -- No. Remember that the fundamental is one complete wave, over and back, and that any harmonic or overtone is an integral multiple of the fundamental.

Is it possible to vibrate the spring in an odd number of segments?

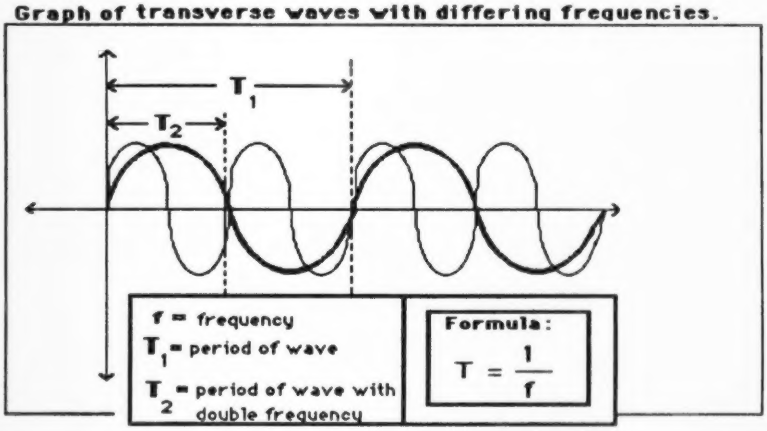
Answer -- Yes. At this point you need to establish some ground rules. For example, if you show a diagram with two ups (Crest) and one down (Trough) will you expect the student to interpret this as one and one-half waves or three waves? Remember, the fundamental is one crest and one trough and we call that one complete wave, over and back. The next wave in sequence is the second harmonic. It vibrates in two parts and it would then have twice the frequency (2f) with two crests and two trough; the third, three times the fundamental frequency (3f) with three ups and three downs; the fourth, 4f, etc. The best approach may be to ask what part of a standing wave is shown or how many standing waves are shown.


HARMONICS
a
b
c
d
A
N
w=2· L
w = L
w= 2/3 L
w= 1/3 L
L represents length of string.
w represents wavelength.
A represents the antinode.
N represents the node.

Transparency Set 1. Each string represents an increasing harmonic from the first to the fourth.

Rule 2: Be consistent between models and interpretations. Make exceptions only when everyone understands the exceptions and the need for the exception.

Graph of transverse waves with differing frequencies.


T_1
T_2
f = frequency
T_1 = period of wave
T_2 = period of wave with double frequency
Formula:
$T = \frac{1}{f}$

What is the relationship between the frequency and the period of the waves in the spring?

Answer -- The greater the frequency, the shorter the period. If the frequency (f) doubles, the period (T) is one half as great. The relationship is inverse, $T = 1/f$.

What is the relationship between the way a wave approaches a fixed node (the hand in this instance) and the way it returns from the fixed node?

Answer -- If it approaches in an UP (crest) position, it returns in a DOWN (trough) position. This is a good place to informally introduce incidence and reflection, and the relationship between the angle of incidence and the angle of reflection.

What is the frequency of the spring in Hz?

Answer -- It varies with how the spring is being moved. Count the number of crests and troughs and double to get the result.

How would you determine the wavelength of the wave?

Answer -- The wavelength of the fundamental (n) is twice the distance between the students who are using the spring. The wavelength of the second harmonic (2n) is equal to the distance between students or one-half the wavelength of the fundamental. The wavelength of the third harmonic (3n) is two-thirds of the distance between students but only one-third of the fundamental wavelength. This is confusing so the best way to determine wavelength is to measure the distance between any two corresponding parts on the wave.

An advertised stereo special indicates that a unit has a "response of 10 Hz to 20 KHz." What does this mean?

Answer -- The lowest frequency that the unit is capable of producing is 10 vibrations (waves) per second (Hz) while the highest frequency which can be produced by the unit is 20,000 vibrations (waves) per second (Hz).

DEFINITIONS:

Transverse Wave: A transverse wave is a wave in which the motion of the disturbance is at right angles to the direction of propogation of the wave. The motion of the spring is up and down while the direction of the wave is at right angles to this motion. Water waves and waves in springs and ropes are examples of transverse waves.

Wavelength: The distance between corresponding points on the wave. For example, crest to crest or trough to trough. (Symbol λ)

Frequency: The rate at which waves are produced. Frequency is measured in Hertz (Hz). One Hz is the equivalent of one cycle per second or one vibration per second. The symbol for frequency is f.

Crest: A crest is the point of maximum displacement of the wave (spring) in the upward direction. The displacement is measured from an imaginary line which would connect your hand and the student's hand.

Trough: A trough is the maximum displacement of the wave (spring) in a downward direction. The displacement is measured from an imaginary line which would connect your hand and the student's hand.

Node: A node is a point on a wave which does not move.

Anti-node: An antinode is a point on the wave which has the greatest amount of movement. An antinode is a crest or a trough.

Amplitude: The amplitude of a wave is its maximum displacement from normal rest position. The amplitude of a wave depends on the amount of energy required to produce the wave. Generally, the greater the energy required to produce a given wave, the greater the amplitude.

Period: The period of the wave is the amount of time required for one up and one down movement of the wave (spring). The symbol for the period is T.

Vibration: A vibration is an up-and-down, side-to-side, or back-and-forth motion of a wave or mass. The motion is generally considered to be periodic or repetitive.

Overtone: An overtone is the vibration of a wave in integral segments (1, 2, 3, 4, 5, etc., parts.)

PROBLEMS

In the introductory activity, great care was taken to introduce the students to the specialized vocabulary of wave motion. That activity contained a number of concepts which need to be developed further. One means of doing this is to take some time to apply the definitions in a more formal setting.

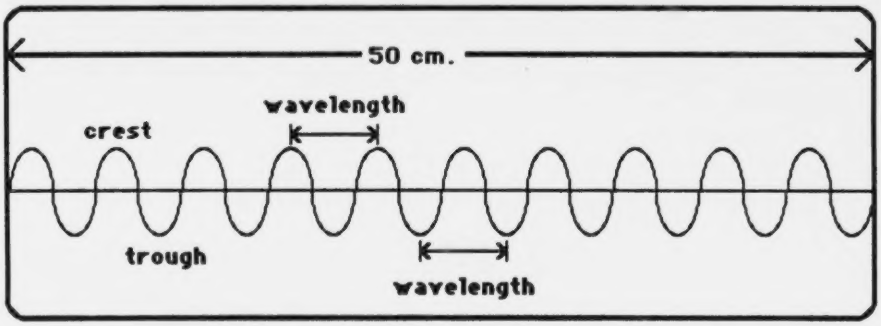


FIGURE 1: TRANSVERSE WAVE

Figure 1 shows a series of transverse waves produced by a regularly vibrating source. Our definition is that a complete wave consists of one crest and one trough. The horizontal distance from any two successive corresponding points on a crest or trough is called the **Wavelength** of the wave. In the figure, ten crests and ten troughs are shown. Therefore, ten waves occupy the space which has been measured to be fifty (50) cm.

If ten waves fill a space of 50 cm, how long is each wave?

Every time a math problem is introduced, you can hear the moans and groans that this is supposed to be a science course and not a math course. And so it is. The best approach is to use what the students know and then move to math as a short cut. Have them remember that a wave consists of one trough and one crest and to count the number of pairs of crests and troughs from the source to the marker. Each pair represents one wave -- trough, crest, trough, crest, etc., through ten waves. Since the distance from the source to the marker is 50 cm, the space occupied by one complete wave of the wave train is 5 cm.

Answer -- 50 cm/10 waves = 5 cm/wave In more conventional form, the wavelength is 5 cm.

This is a fairly straightforward solution but it is important for several reasons. First, the idea of dimensional analysis or unit analysis is continued from earlier studies, and secondly, although the numbers and problems may become more complex, the notion that the wavelength of waves of any sort is determined in the same way is established; i.e., the total distance divided by the number of waves equals the **Wavelength.** The Greek letter lambda, λ, is used to designate the wavelength. (So, it doesn't harm students to teach them a little more Greek in physical science.) Thus, the expression $\lambda = 5$ cm indicates a wave which has a wavelength of 5 cm.

FREQUENCY

Again, using Figure 1, assume that the ten waves were produced in ten seconds.

How many waves are produced in one second? Since the numbers are simple, 10 waves in 10 seconds, it is easy to point out the one to one correspondence between wave production and time. One wave in one second.

Answer -- 10 waves/10 seconds = 1 wave/second.

Even when the numbers are more complex, the same basic relationship remains. The total number of waves divided by the time represents the number of waves produced per unit time. This value represents the FREQUENCY of the wave. Waves produced at the rate of 1 wave per second would have a frequency of 1 hertz, (Hz). The letter f is used to represent the frequency of a wave. The expression $f = 1$ wave/sec is equivalent to $f = 1$ Hz, and $f = 50$ waves/sec would mean the same as $f = 50$ Hz.

PERIOD

It is often desirable to know how much time is required to produce a wave. For example, if one wave is produced each second, then one second is required to produce a wave. Similarly, if five waves are produced per second, it would require one second to produce five waves. The rate at which waves are produced is called the **period** of the wave, T.

What is the period of a wave if 5 waves are produced each second?

Answer -- One second is required to produce 5 waves. Therefore, $T = 1$ sec/5 waves = .2 sec/wave. The meaning is that .2 sec are required to produce each wave.

The relationship between the period (T) and the frequency (f) is: $T = 1/f$.

WAVE VELOCITY

Now, let us refer to Figure 1 once again. Assume that the ten waves were produced in five seconds. How quickly do the waves move from the source to the marker which is placed 50 cm away? The simple way to solve the problem is to show the relationship between distance and time, that is, the velocity* (v) is equal to the distance (s) divided by time (t).

$v = s/t$, $v = 50$ cm/5 sec, or $v = 10$ cm/sec

However, we seldom make things this simple, otherwise the students would know all of the answers. We usually say something like: "A wave has a wavelength of 5 cm and a frequency of 2 Hz. Find the velocity." This warps minds, especially if you are not into waves. If we think about this for a while, we realize that one wave (which takes up a space of 5 cm) moves past a given point in 0.5 sec (since $T = 1/f$) and that the same relationship, $v = s/t$, can be used; i.e.,

$v = 5$ cm/.5 sec = 10 cm/sec

In fact, if we use the relationship $v = \lambda/T$, modified by writing $v = \lambda/1/f$, and solving it, we can write $v = f\lambda$, and solve the problem as:

$v = f\lambda$
$v = 5$ cm/wave x 2 waves/sec
$v = 10$ cm/sec

*(Note that the terms velocity and speed are used interchangeably here. In a strict sense, the direction is given in the diagram and it is assumed that this is the direction of motion.)

SUMMARY

Now, the purpose of this discussion has been to provide the basic concepts associated with wave motion, and to do it in a telling rather than a doing way.
The whole explanation has become somewhat confusing in the process. Although the concepts are relatively straightforward, the explanation, whether oral or in written form, can become cumbersome to the listener or reader. Consequently, the following rule should be followed.

Rule 2: It is easier to learn concepts if a physical model can be used by the learner to identify the ideas and to unify the concepts.

The demonstrations and activities which follow in this unit can be used to help students understand and internalize the ideas associated with wave motion.

WATER WAVES
Demonstration

The single best piece of equipment available for the study of waves is the ripple tank. Such a device, brought to the attention of physical science and physics teachers as a result of the PSSC materials developed in the late 1950's and early 1960's, was actually used almost two hundred years ago by Thomas Young. He utilized the device as a visual aid during his lectures on wave motion. The materials used in its construction have changed considerably over the years but it remains basically the same -- a container with a transparent bottom is filled with water to act as a medium, a vibrating wave generator or dipper, and a source of light, either above or below, to cast shadows of the waves produced in the tank.

If a ripple tank is not available, a suitable substitute is a clear plastic shoe box or storage box placed over the protected surface of an overhead projector. You can use a pencil or your finger for the wave generator. If such an arrangement is used, make sure that no water can get into the electrical circuit of the projector! Accidentally spilling water into the projector wastes overhead projectors and physical science teachers.

Caution: Spilling water on an overhead projector is dangerous to your health!

If you have used a ripple tank, you have probably experienced the frustration of regulating the frequency of the vibrator to produce standing waves in the tank. However, the purpose of the activity is not to be especially scientific about the phenomena but rather to introduce the notion of diffraction, refraction, interference and reflection and, for this purpose, it is worthwhile to endure some frustration.

PURPOSE

The purpose of this activity is to observe the behavior of water waves and to develop a model which illustrates some of the behavior of light. In the introductory remarks it was indicated that a controversy surrounded the nature of light. Proponents of the particle theory argued that light traveled in straight lines and they used the properties of reflection of light as one of the major tenets of the particle theory. It made sense. If a ball is thrown against a solid wall it bounces back. If the incident ball is at right angles to the surface, it is reflected at right angles, i.e., it returns to the thrower. If the ball is thrown at an angle to the surface, the ball is reflected at that same angle (with respect to the normal to the surface) away from the thrower. The phenomena of refraction was a little more difficult to explain, but since the speed of light had not been measured it was simple to argue that the speed of light was greater in materials which were more optically dense than air. This was also reasonable. The proponents of the particle theory did not rely exclusively on defending their position. For example, no one had observed diffraction or bending of light rays around the corners of objects when shadows were produced. The adherents to the particle view held that their view of the straight line motion of light was correct since sharply defined shadows can be found in nature.

In this demonstration we will attempt to duplicate some of the same phenomena used by Thomas Young in his efforts to popularize the wave theory. Reflection, refraction, diffusion, and diffraction will be examined and we will look carefully at constructive and destructive interference.

Have students recall the characteristics of transverse waves and use the terminology of transverse waves. If they have studied sound in the interim, have them recall the phenomena of beats -- where two sounds destructively interfere to produce intervals of no sound and where sounds constructively interfere to produce a louder sound. (If they have not studied sound yet, don't worry -- we can work around that.)

For openers, tell them that two lights can shine together to produce intervals of no light. That should bring on a round of hiss-boo. Ask them to hold their index and middle fingers together as closely as possible and still leave a thin slit between the fingers. They will need to use the fingers of the other hand to brace the two fingers to get the thinnest slit possible. Now, tell them to hold the fingers near and parallel to their eye and to look at a light. Ask them what they see. At first, only one or two students will be able to see the alternating bands of light and dark. They are very thin bands. (You might also tell them that they can get the same effect if they close one eye and almost close the other and look at a light.)

You might also warn them not to try this during any class except for physical science because other teachers will think they are trying to sleep.) The reason that they haven't observed this phenomena when two different sources of light are used is that the sources must be in phase. This means that the waveforms of the two sources must be exactly the same. Now introduce the ripple tank by telling them that we are going to examine the characteristics of waves on a larger scale and then come back to this idea. In fact, we will be measuring the wavelength of light with some very crude apparatus (a meter stick.)

The ripple tank demonstration is an excellent learning experience for students but it can deteriorate to a "nothing" exercise if the students are inattentive. Be sensitive to the class atmosphere and keep the students on task during the demonstration.

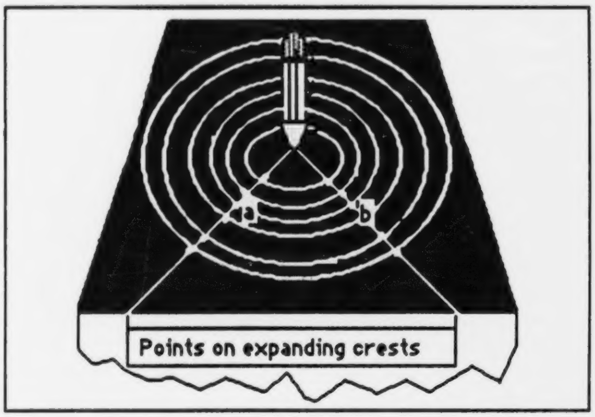
MATERIALS

Ripple Tank with light source
Large piece of paper to cover the area under the ripple tank

ALTERNATE MATERIALS

Overhead Projector
Clear Plastic Shoe Box or clear plastic storage box
Clear plastic or glass to cover and protect the top of the overhead projector
Large piece of paper to use as a screen

Set up the ripple tank (or overhead projector tank) and arrange the students so that they can observe what is happening. If the overhead projector arrangement is used, make sure that there is no way that water can get into the projector. The bulb is extremely hot and an explosion will take place if water gets on the bulb. Therefore wear safety goggles for this demonstration.

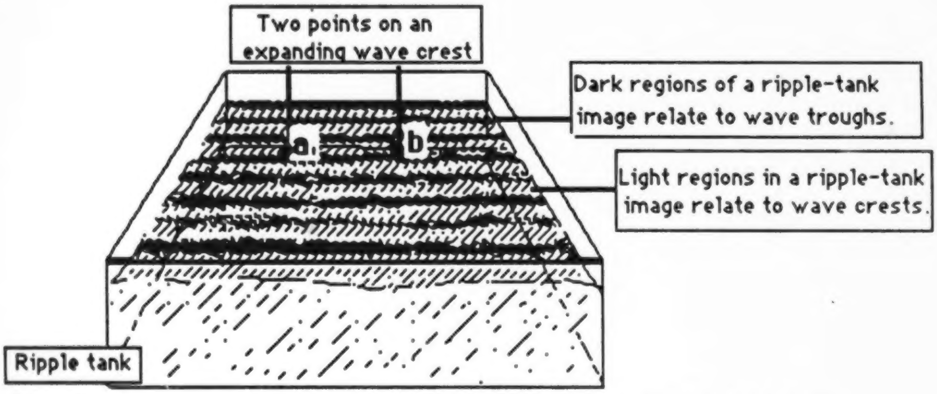


Periodic circular waves generated by a point source in a ripple tank.

PROCEDURE

1. Use your finger or a pencil eraser to dip in the water. The shadow which is produced shows the wave pulse as it moves across the tank. What is the shape of the pulse? (Circular.) How is the wave reflected? (As circular waves which appear to have been generated as far behind the tank wall as the original wave was from the wall when it was generated.) Do the wave fronts appear to become more nearly parallel (straight) as they get further from the source? (Would light from the sun reach the earth as essentially parallel rays?) How do the

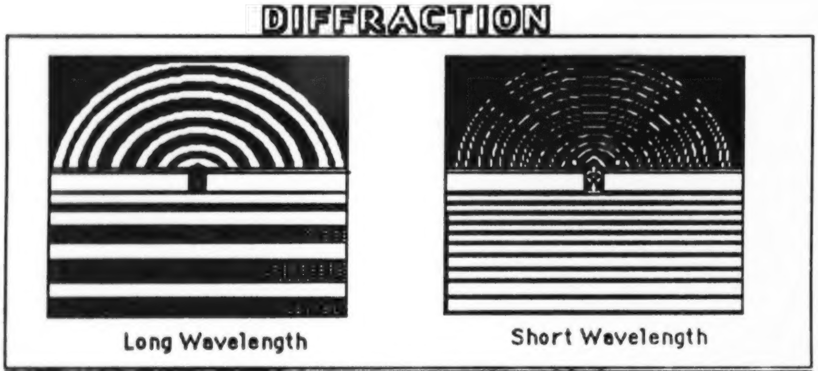
waves and the reflections interact? (If the vibrational motion is sustained, a series of interference patterns develop with some dark regions and some light regions. The light regions are crests which act much as magnifying lenses (Convex) while the dark regions are troughs which act as diverging or concave lenses.) Talk the students through these observations since the interference patterns will be important during later discussions. Use two point source generators to produce two waves. Go through the same series of questions. Is there a difference in the way the waves interact? What happens when a regular set of waves is produced? Do the basic interactions still hold? (Notice how one set of waves interferes with the other and how a regular pattern is established.)


Two points on an expanding wave crest
a
b
Dark regions of a ripple-tank image relate to wave troughs.
Light regions in a ripple-tank image relate to wave crests.
Ripple tank

Periodic straight wave moving across a ripple tank. Wavelength is the distance between adjacent troughs.

2. Use the parallel wave generator to make long waves parallel to the sides of the ripple tank. How are these waves reflected and how do they interact? Move the wave generator so that the waves are produced at an angle to the long side of the tank. How are these waves reflected? How do they interact? Are regular patterns produced? Can you identify nodes and antinodes? What about standing wave patterns? Remember, the idea is to cause students to observe, discuss, and record the phenomena. Neither you nor the student will be expected to become an expert on waves.

DIFFRACTION



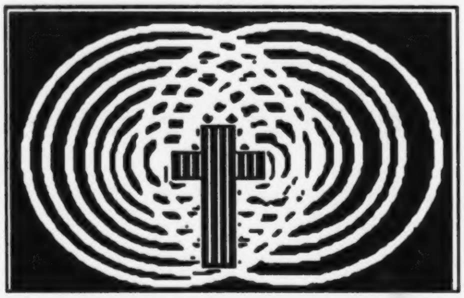
Long Wavelength

Short Wavelength

A decrease in the diffraction occurs as a periodic straight wave sent against the barrier is shortened.

3. Now introduce a barrier with a small opening in the center. In a shallow tank, two wood blocks work nicely. Generate the circular waves again. What happens when the waves reach the opening? Does a new wave appear to be generated at the opening? Remove one of the barriers. How does a wave react when it passes the barrier? What happens when you use the straight wave generator? Do new waves appear behind the barrier? Use three small barriers. Are these slits (openings) the source of new waves? How do they interact? Do you see patterns of dark and bright lines?

WAVE PATTERN IN RIPPLE TANK



Interefering Waves cancel each other at the centers. As they expand and cross, they strengthen themselves.

As the new waves are generated at the openings, the phenomenon of diffraction, or bending, is being illustrated. The interference patterns of bright and dark bands are analagous to the bright and dark bands that the students observed through the finger slits. By moving the barriers around, the students can manipulate the angle of incidence and reflection of the waves. One way to get a permanent record of these events is to use a felt tip pen to trace the interactions on the paper. It will take only a few minutes to get a record for each group. Have the students record as many observations as they can about the waves and the interactions.

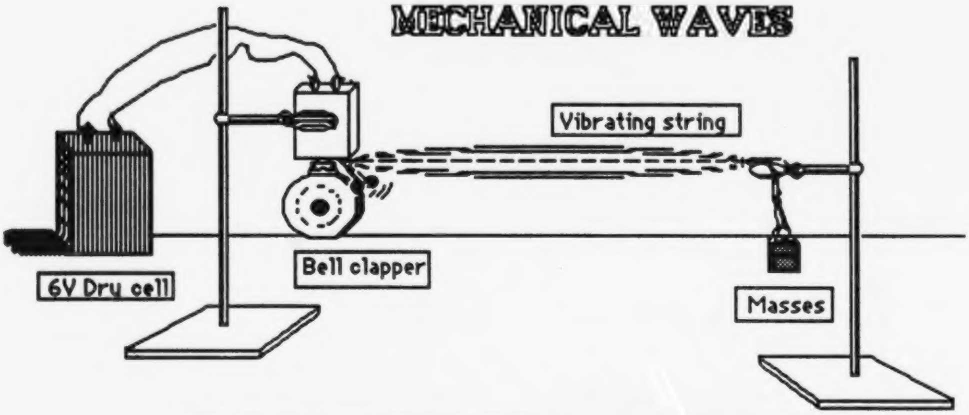
4. During the observation of waves in the ripple tank the students were able to see how waves are reflected; how they interact to produce dark and bright areas: and how the openings between the barriers act as new souces for a set of waves. They were able to see how the waves were diffracted or bent around the edges of the barriers. They learned that two sets of waves could also be superimposed -- that is -- two sets of wave trains could cross the path of each other and continue undisturbed after they had interacted. This is totally unlike water streams or streams of particles which are deflected when they are made to interact. These basic ideas of how waves are produced and how they interact were important components in the arguments which popularized the wave theory of light.

Ask the students to recall our strange use of the finger slits to observe the bands of dark and light. Also have them recall the nodal lines -- bright and dark areas produced by the interaction of waves -- emerging from the two openings between the barriers in the ripple tank.

Have them perform the finger slit exercise again and to think of any possible way that the dark and light bands between the fingers could be related to the interference of light waves. (One possible explanation might be that the light is reflected back and forth between the fingers and that the bands are produced by the interaction of the reflected light. Another possible explanation might be that the light interferes because of diffraction since the wavelength of light may be very short compared to the thickness of the fingers.) If there is no connection at present don't be surprised because it took many years for scientists to accept the significance of the original experiments. (If you feel uncomfortable in discussing this, don't worry. The best high school teacher I ever had learned with us. That teacher was confident enough to know that all of us, including the teacher, could learn if we worked on the problems and continued to ask "Why?" of each other and then tried to find the answer.)

MECHANICAL WAVES

(Bell Clapper Method)
Laboratory Exercise
--for the teacher--



As the bell clapper moves, the string vibrates in standing waves.

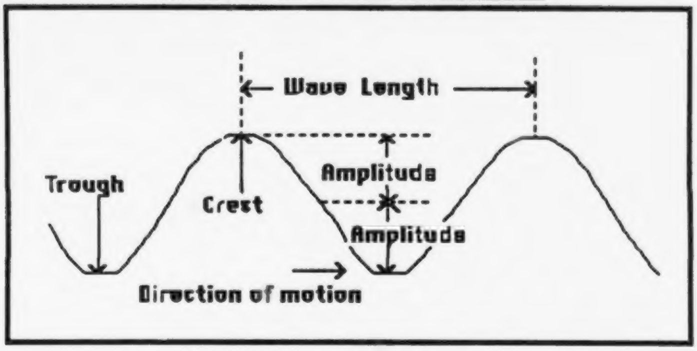
PURPOSE

The purpose of this lab is to develop a working definition of wave terminology, to measure selected parts of transverse waves, and to determine which variables produce different wave forms.

At the conclusion of this laboratory exercise the student should be able to:

1. Properly wire an electrical circuit.
2. Use the vibrating arm on the bell to produce standing waves in a string.
3. Measure the wavelength of the fundamental wave.
4. Explain how it is possible to produce waves of varying lengths by using the same bell and the same battery.
5. Predict the wavelength of the 1st, 2nd, and 3rd overtones of the fundamental.
6. Devise a method to determine the frequency of the fundamental.
7. Use the value obtained for the frequency (or the value assigned by the teacher) to determine the period of the fundamental.
8. Use the measured or assigned value of the frequency to calculate the velocity of the wave in the string.
9. Differentiate between the direction of motion of the string and the direction of motion of the wave and explain the meaning of the term TRANSVERSE WAVE.
10. Identify:
    a. Wave
    b. Wavelength
    c. Crest
    d. Node
    e. Trough
    f. Antinode

Mechanical Waves



The Shape of a Wave

MATERIALS

- Bell with clapper
- 6ft length of medium weight string
- 6 volt power supply (Dry cell or lab volt)
- 2 ring stands with clamps or other means of suspending the bell and string
- Meter stick
- Hook-up wire for the battery
- Assorted masses with hooks

PRELABORATORY DISCUSSION

What is the difference between surfing "waves", sound waves, and light waves? What kinds of waves are received by radio and TV sets? How can a laser be used in surgery or how can a light beam transmit almost 18,000 telephone conversations at a time? Why is copper wire becoming obsolete in long distance telephone lines and why will woodpeckers need to go back to natural trees for a place to peck? Understanding the answers to these questions will require a knowledge of the basic principles of wave motion.

For openers, a surfing "wave" is not really a wave! As the water gets shallow, the forces which drive the waves in deep water cause the water to "pile up" on the beaches as energy is released quickly over a short distance. In areas like California and Hawaii where the nearshore depth of the water is great (until it reaches the beaches) and where the fetch or distance the waves travel is great, the surf can be fantastic. On the other hand, the Gulf of Mexico area is generally shallow for great distances seaward and the energy of the waves is dissipated over a much greater distance. The gradual release of the energy limits the amount of water which can be lifted onto the beaches.

That's freebie -- it doesn't have anything to do with waves but the students always ask so it is best to get it out of the way when you can. It is always a good idea to use an example from real life whenever possible to get and maintain the interest of the students.

You probably realize that you have used your best lab on wave motion when you used the coiled spring. My experience is that students simply mimic what you have demonstrated if the coil spring exercise is used again for a lab activity. It helps to use an activity where the students have to ask "why" or "what" or "how" of themselves as they solve a problem or gather information. One way to provide a real "what, why, how" lab on waves is to use a battery driven electrical bell to generate waves in a string.

This is a deceptive lab and few students will realize at the outset that, with a given battery and bell, the frequency of the bell clapper will not vary appreciably when the battery is used for short periods of time. This of course means that the frequency of the waves produced in the string cannot be changed unless the period of the clapper is changed by:

1. Changing the length of the clapper, or
2. Increasing the mass of the clapper or the mass of the string, or
3. Increasing the tension on the string, or
4. Varying the voltage of the battery, or
5. Using a combination of the above.

The first thing that the students will find is that the fundamental is easy to produce but that frequencies other than the natural fundamental and the overtones of the fundamental of the bell are almost impossible to obtain. By the time most of the students recognize the difficulty, the class will be almost over. Get them back into the large group and compare the motion of the bell clapper to the motion of a pendulum. Ask them what single thing they could do to change the period of a pendulum. Do not carry the analogy too far since you will also want to ask them how an added mass would effect the ability of the battery to lift the clapper. How would they change the pitch of a guitar string? (When someone suggests using a heavier string or increasing the tension, have those groups try these ideas during the next session.)

Have each group introduce at least one variable (lengthened clapper, heavier string, heavier clapper, adding additional masses to the end of the string, etc.) during the next run. Does the length of the string have anything to do with the wavelength or does it simply give additional overtones of the fundamental? A homework assignment might be to have the students draw a sketch of the arrangement of the variable and to write out a prediction of the effect of the variable on the wavelength and, hence, the frequency.

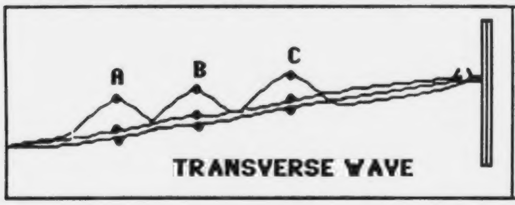
These are only a few of the many assignment options open to you. Take advantage of these. Make the students think and apply!

PROCEDURE

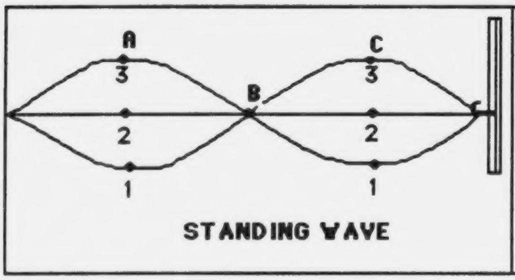
It is probably best to walk the students through the activity first so that they understand the physical set-up. Basically, a string is attached to the bell clapper and the fingers grasping the free end of the string are moved along the length until a standing wave is produced. They should be able to point out the wave parts -- the crest, trough, wavelength, etc. -- and will probably be in a hurry to get on with their activity. Do not spend a lot of time explaining the procedure. Let them discover that there is a little bit more to it than is at first apparent.

1. The materials are generally available from stock. If you don't have enough bells with clappers you might ask the physics teacher to let you use a couple of them. You will need enough to have not more than four students per group -- three per group is better. (Your friendly local K-Mart, hardware, discount store or similar retailer has these "buzzers" for a couple of bucks each -- good investment.)
2. If the students do not know how to connect the wires to the bell, you will need to demonstrate how to do the hook-up. Make sure that you demonstrate proper safety precautions, especially if a power supply is used instead of a 6v dry cell battery.
3. Be sure that you bend the clapper away from the bell far enough so that you do not have ten doorbells sounding -- you are after the motion of the clapper, not the noise.
4. Attach one end of the string to the clapper and hold on to the free end of the string until the correct length for the fundamental is determined. The best arrangement is to secure the bell with one test tube clamp and the other end of the string (under slight tension) with another test tube clamp. (A simpler way is to hang the free end of the string over a clamp and hook a weight on it.)
5. Once the proper length for the fundamental is determined, the test tube clamp can be moved into position and the string draped over the clamp. A small mass should be attached to the end of the string to maintain the proper tension.
6. Have the students set up the apparatus as directed. It will be apparent if they are having problems. Guide them but let them do the work.
7. Students should be able to answer these specific questions:
    a. What is the name of the wave which vibrates in one part?
    b. Sketch the wave and label the: crest, trough, antinodes, nodes, wavelength, amplitude, and normal rest position.

MECHANICAL WAVES



By moving one end of the string, a wave moves down the string. The crest passes from point A to B to C.



This string is vibrating in two whole loops. The points A and C represent the antinodes. The point B represents the node.

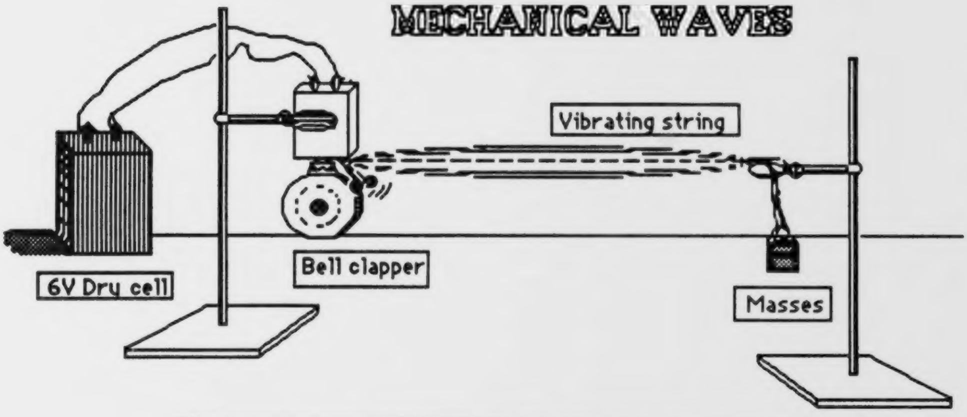
   c. Predict and then determine the length of the 1st, 2nd, and 3rd overtones.
   d. Show how the direction of motion of the string differs from the direction of motion of the wave.

8. Now ask to change the wavelength of the fundamental and the fun will probably start. They will want answers and you will need to get them thinking as indicated in the discussion above. If you feel that you have the time during the same session, the students may be able to complete the lab. If not, continue the lab to the next class period.
9. Be sure to work in the questions about the frequency and velocity of the waves. Have them make the calculations either during the lab or as part of a seatwork assignment. If you have time, you may want to ask them to devise a means of actually determining the frequency of the waves and then calculating the velocity. As a matter of fact, how would you determine the frequency of the waves???

POSTLABORATORY DISCUSSION

Go over the basic terminology. Find out what problems the students had in setting up the lab. What caused them the most problems? How did another group resolve that problem? Did all of the groups get the same results? Elicit reasons why the students think their answers were different from the answers of other groups. What variable(s) was/were most successful in producing differing wavelengths? Was there an apparent upper or lower limit to the number of waves which could be produced with the length of string available?

MECHANICAL WAVES
(Bell Clapper Method)
Laboratory Exercise
--for the student--



As the bell clapper moves, the string vibrates in standing waves.

PURPOSE

The purpose of this activity is to develop a working definition of wave terminology, to measure selected parts of transverse waves, and to determine which variables produce different wave forms.

In the demonstration with the spring, you learned the basic terminology associated with transverse waves. This activity will give you some experience in using the terminology and some practice in solving problems.

MATERIALS (Per Group)

Bell with clapper
6ft length of medium weight string
6 volt power supply (Dry cell or lab volt)
2 ring stands with clamps or other means of suspending the bell and string
Meter stick
Hook-up wire for the battery
Assorted masses with hooks

BEFORE YOU START

This is one of those labs where it is best to read the directions carefully before you get carried away with your brilliance. Make sure you understand how to connect the buzzer and the power supply before you start.

PROCEDURE

Basically, a string is attached to the bell clapper of a vibrating type buzzer and the other end of the string is attached to a small mass. The whole works is supported by two ring stands and clamps -- the buzzer by one clamp, and the free end of the string by another clamp. Adjust the distance between the ring stands to match the length of a standing wave. You determine this distance by lightly grasping the free end of the string with your fingers and moving them along the length until a standing wave is produced. Move the other support to this point and make your final adjustments to get the best standing wave. You should be able to point out the wave parts -- the crest, trough, wavelength, etc. Don't get in a hurry and fail to identify some of the parts of the waves.

1. What is the name of the wave which vibrates in one part?

2. Sketch the wave and label the:
   - crest
   - trough
   - antinodes
   - nodes
   - wavelength
   - amplitude
   - normal rest position

3. How does the direction of motion of the string differ from the direction of motion of the wave? Draw an arrow on your sketch of the wave to show the direction of motion of the wave. Label this arrow "wave direction." Draw an arrow on your sketch of the wave to show the direction of motion of the string. Label this arrow "string direction."

4. Predict and determine the length of the 1st, 2nd, and 3rd overtones by making the string vibrate in 2, 3, and then 4 separate parts. Measure these distances and record them on your paper. Write a description of how you produced each of the overtones.

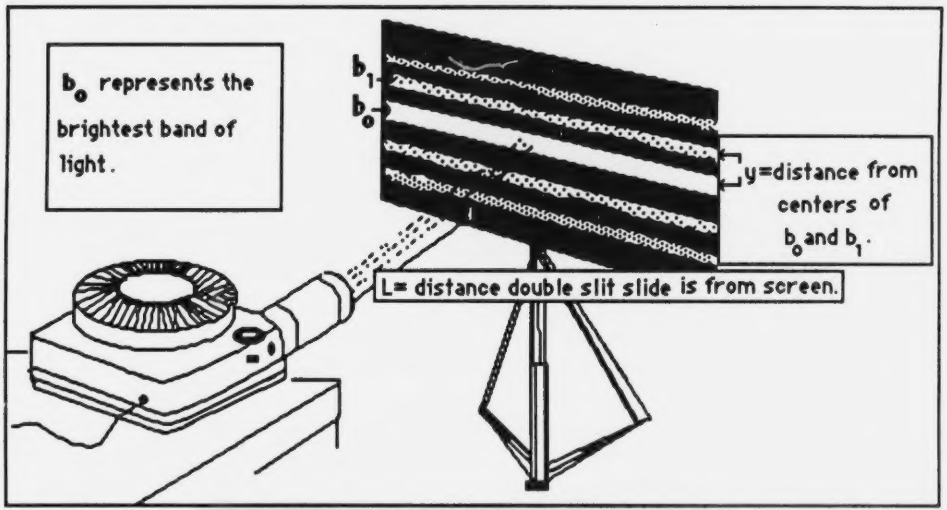
5. How would you change the frequency of the fundamental? Write a short explanation of how you would do this. Now make the changes in your apparatus and explain how you know that the frequency has been changed. Write your explanation on your paper.

6. Can you change the wavelength of the fundamental? How? Write an explanation of how this could be accomplished. Try your theory. Does it work? If your idea worked, explain what you did to change the wavelength. If it did not work, explain why you think it did not. Write the appropriate explanations on your paper.

Take the equipment down and put it in the appropriate storage area.

INTERFERENCE PATTERNS IN LIGHT

(Thin Slits Method)
Laboratory Exercise
--for the teacher--


b_0 represents the brightest band of light.
b_1
b_0
y=distance from centers of b_0 and b_1.
L= distance double slit slide is from screen.

SINGLE-SLIT DIFFRACTION OF LIGHT

PURPOSE

The purpose of this activity is to produce interference patterns with light waves in much the same way that interference patterns were produced with water waves. Set up and conduct an experiment to demonstrate interference patterns of light (for all students.) The advanced students can measure, by indirect means, the wavelength of light. Remember you will need to use the formula, wavelength = (dy/nl), if the 2nd, 3rd,.....or nth bright line is used. The order is counted from the center of the middle or 0th bright line.

MATERIALS

Meter stick	Or:	Heavy duty aluminum
Slide projector or other high intensity light source		Razor blades
Assorted colored filters		Two 35 mm slide mounts or
Single and double slit slides		posterboard

PRELABORATORY DISCUSSION

During the observation of waves in the ripple tank, the students were able to see how waves were reflected; how they interacted to produce dark and bright areas; and how the openings between the barriers acted as new sources for a set of waves. They were able to see how the waves were diffracted or bent around the edges of the barriers. They learned that two sets of waves could also be superimposed -- that is -- two sets of wave trains could cross the path of each other and continue undisturbed after they had interacted. This is totally unlike water streams or streams of particles which are deflected when they are made to interact. These basic ideas of how waves are produced and how they interact were important components in the arguments which popularized the wave theory of light.

Ask the students to recall our strange use of the finger slits to observe the bands of dark and light. Also have them recall the nodal lines -- bright and dark areas produced by the interaction of waves -- emerging from the two openings between the barriers in the ripple tank.

Have them perform the finger slit exercise again and to think of any possible way that the dark and light bands between the fingers could be related to the interference of light waves.

One possible explanation might be that the light is reflected back and forth between the fingers and that the bands are produced by the interaction of the reflected light. Another possible explanation might be that the light interferes because of diffraction since the wavelength of light may be very short compared to the thickness of the fingers.

PROCEDURE

1. Hold or tape two razor blades (or disposable scalpel blades) together and cut two paralleled slits about 1.5 cm long in a section from a thin aluminum pie pan or piece of heavy duty foil. Trim the section to fit into a 35 mm slide frame. If slide frames are not available, you can make a substitute from a piece of posterboard. After inserting the aluminum into the mount, carefully separate the slits so there is no overlap. Measure the separation of the slits as closely as possible, i.e., 0.1 mm, 0.50 mm, 0.25 mm, 0.125 mm, etc. (This is also a good estimation exercise for the students since the smallest scale they have is probably marked in mm.)
2. Cut the single slit 1.5 cm long in the second piece of aluminum foil and mount it in another 35 mm slide frame. If your are using colored cellophane for the filters, cut a triple layer of the cellophane and mount it in a 35 mm slide mount. Place the color filter in the slide projector. This will provide a near monochromatic light source for the exercise. Hold the single slit slide in front of the projector lens. Position the double slit slide in the light which passes through the single slit mount. Note the pattern which is produced on the screen or wall. (See diagram above.)
3. If everything has gone properly to this point, you should have a series of light and dark bands projected on the wall. Since there are only two slits in the foil, the extra light and dark regions have to be explained. That is all there is to it except for the explanations and the measurements. The derivation of the formula to determine the wavelength of light is probably not worthwhile for most physical science students. (If they really want to know, give them an assignment to look it up in a physics text, or have a physics text available so that you can discuss the derivation with that group while other students work on something else.) For now, we will assume that the following approximate relationship is true.

$\lambda = (dy/L)$ where
d = distance between the double slits
y = distance from the center of the center of the center bright line, to the center of the 1st, 2nd, or 3rd bright line*
L = distance from the double slit slide to the screen

CONCLUSION

Each of these quantities is easily measured and the numbers, although a pain to work with, are relatively easy to handle with a calculator. The values should range between 0.000035 cm for the violet end of the spectrum and 0.000070 cm for the red end of the spectrum. It is not likely that the students will get answers in this range although sometimes, like miracles, it does happen.

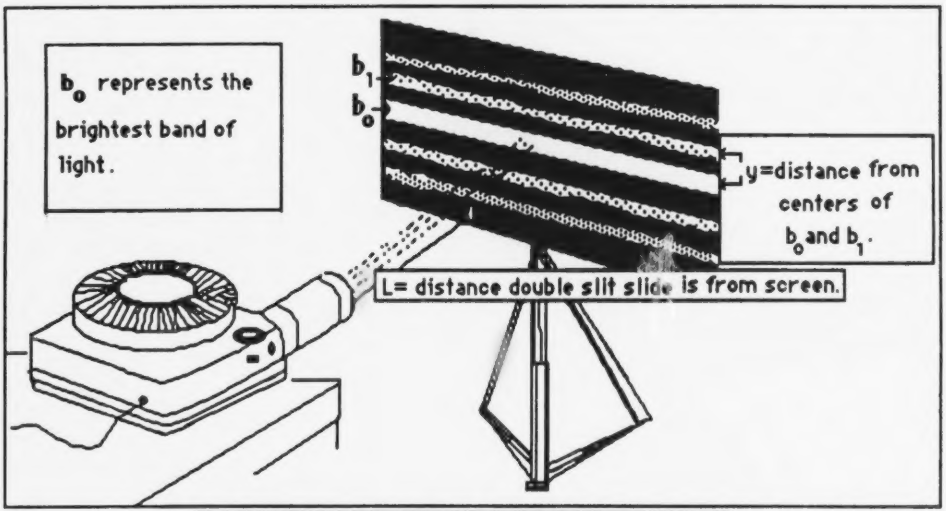
POSTLABORATORY DISCUSSION

Have students recall that the single slit opening in the ripple tank was represented by the pencil or finger which generated only one set of waves. That is the purpose of the single slit mount -- to provide a single source of light. Just as the water waves moved out from the single source, the single slit mount provides a line source for light. The water moved out from the generator in a circular pattern until it reached the barriers with two openings between them. When the water reached the two openings, another set of waves was produced and these, in turn, interacted to produce a series of dark and light patterns. The same thing happens with the light waves. The light moves from the line source until it reaches the double slit. From there, the light spreads out in two sets of waves which are from essentially the same source. These two sets of waves interact to produce the series of bright and dark regions on the screen. Observation of the phenomena is worthwhile even if the calculations are not made. The basic notion is that light behaves as if it has wave characteristics.

The point is that relatively simple measurements, coupled with a brilliant idea, are often used to advance the understanding of scientific knowledge. Once an idea germinates and it has possibilities, the main problem is to refine the process and/or equipment to get better and better approximations to the ultimate answers. Keep in mind that we still do not know the exact speed of light and that we still do not know exactly how the nucleus of an atom is arranged. We have approximations and we have models but we have not arrived at truth. Sometimes this is worth remembering.

INTERFERENCE PATTERNS IN LIGHT

(Thin Slits Method)
Laboratory Exercise
--for the student--


b₀ represents the brightest band of light.
b₁
b₀
y=distance from centers of b₀ and b₁.
L= distance double slit slide is from screen.

SINGLE-SLIT DIFFRACTION OF LIGHT

PURPOSE

The purpose of this activity is to produce interference patterns with light waves in much the same way that interference patterns were produced with water waves.

Objectives:

When you have completed this activity you should be able to:

1. Describe an experiment which demonstrates interference patterns of light.
2. Measure, by indirect means, the wavelength of light.

MATERIALS (Per Group)

Meter stick
Slide projector or other high intensity light source
Assorted colored filters
Single and double slit slides
or:
Heavy duty aluminum foil
Two razor blades or scalpel blades
Two 35 mm slide mounts or cardboard mounts of the same size.

BACKGROUND

During your observaiton of waves in the ripple tank you were able to see how waves were reflected; how they interacted to produce dark and bright areas; and how the openings between the barriers acted as new sources for a set of waves. You were able to see how the waves were diffracted or bent around the edges of the barriers. You also learned that two sets of waves could pass undisturbed through one another. The waves, unlike streams of particles or colliding basketballs, were not affected when they ran into each other. From this we can conclude that waves just do not behave like particles.

You might have thought that the "finger slit" exercise was dumb. All you could see when you pressed your fingers together with a small opening left between them was a series of light and dark bands of light. Do the finger slits exercise again. Don't worry, everyone in the room will be looking at a light through their fingers so you shouldn't feel self-conscious about it.

Let's get serious about the dark and light bands. What happens? What makes them form? Why doesn't a series of light and dark bands form when we shine two flashlight beams together? We will attempt to demonstrate the interference patterns in light by using an arrangement which is very similar to the water waves in a ripple tank. Recall that the water waves, when they passed through two openings in the barriers, formed two sets of waves -- one set at each opening and that these new waves interacted to form patterns. In effect, the new waves were produced from a single set of original waves. The new water waves were in phase with the original waves and had the same frequency. That is the key. The new waves had exactly the same frequency. In this experiment, the problem is to use one light source and to produce two beams which are of exactly the same frequency and then measure the wavelength of light from the resulting interference patterns.

PROCEDURE

1. If you have the pre-mounted single and double slit slides, you can skip to the next paragraph. If not -- you have some work to do. Hold or tape two razor blades (or disposable scalpel blades) together and cut two parallel slits about 1.5 cm long in a section from a thin aluminum pie pan or piece of heavy duty aluminum foil. Trim the section to fit into a 35 mm slide frame. If slide frames are not available, make a cardboard frame to hold the aluminum section. After mounting the aluminum foil in the holder, carefully separate the slit openings so that there is no overlap. Now, cut a single slit 1.5 cm long in the second piece of aluminum foil and mount it in another 35 mm slide frame (or cardboard holder.) Cut a triple layer of the cellophane filter and mount it.
2. Measure the separation of the double slits as carefully as possible. Too close to measure? Fake it! Is it 0.5 mm, 0.25 mm or closer to one-eighth (0.125 mm)? Record the measurement on your paper. Express the value in cm and call it "d".
3. Place the color filter in the slide projector. This will provide a near monochromatic (one color) light source for the experiment. You hold the single slit slide in front of the projector lens. Have your lab partner hold the double slit slide in the beam from your slide. You are going to have to adjust the position of the projector, the screen, your slide, and your partner's slide to make this thing work. Adjust the position of all the materials until you can get an image produced on the wall or screen. Then move everything around until you get the best image possible. When you do this you will have not one or two, but several alternating bands of light and dark projected on the screen.

If everything has gone properly to this point, you should have a series of light and dark bands projected on the wall. Hold everything still for a while because you have to take two measurements. First, measure the distance between the center of the middle bright band and the center of the first bright band on the left or right side. Take the measurement in cm and record the measurement on your lab sheet. Call this value "y". Next, measure the distance from the double slit slide to the screen or wall. Make this measurement in cm also and record the value. Call this value "L". Once you have made these measurements, you can put your materials away and get on with the hard part -- thinking.

Since there are only two slits in the foil, how are you going to explain the extra light and dark bands? Think back to the ripple tank experiment. Use the double openings in the ripple tank experiment as a basis of your explanation for the formation of the dark and light bands which are projected on the wall. This is a tough assignment but with your skill and imagination you can handle it easily. If it were not, there would be no reason to have it.

4. There is one other detail to attend to and that is to use the numbers that you wrote down. For now, we are just going to assume that this formula works -- $\lambda = (dy)/L$.

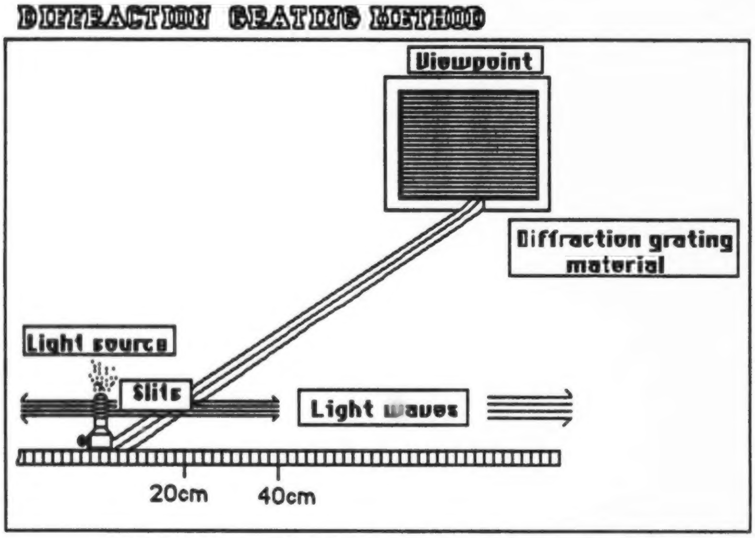
λ = the wavelength of light
d = distance between the double slits

y = distance from the center of middle bright line to the center of the first bright line on either side of it
L = distance from the double slit slide to the screen

Just plug in the numbers and turn the crank and presto -- the wavelength of light magically appears. The answer you get will, of course, be determined by the measurements which you took. Good measurements -- good results. Bad measures -- bad answers. The range of "good" answers is from 0.000035 to 0.000075 cm. What is your percent error? Why do you think your answer is as good as it is? Bad?

DETERMINING THE WAVELENGTH OF LIGHT

(Diffraction Grating Method)
Laboratory Exercise
--for the teacher--



Diffraction method for determining the wave length of the different spectra of light.

PURPOSE

The purpose of the activity is to determine the wavelength of light using the diffraction grating method, which is more accurate than the thin slit method.

MATERIALS (Per Group)

Three meter sticks
Diffraction grating material, mounted in a 35 mm slide frame
Light source, preferably a showcase bulb
Transparent tape or thumb tack
Colored cellophane filters (from biology department)
Tissue or paper towel core

PRELABORATORY DISCUSSION

By the way of review, recall that our first demonstration of the behavior of waves was based on the purely mechanical model of a spring in motion -- essentially wave motion in a horizontal and vertical plane. The second demonstration with water waves moved wave motion into three dimensions although, admittedly, few students were probably impressed with the transition. However, if the ripple tank demonstration was reasonably successful, students should be able to describe the action of waves as they spread from the source; how the waves behaved when they encountered a barrier; and how the waves interacted to form nodal lines when they passed through two or more openings between the barriers. The thin slits activity provided evidence that light waves interact to form a series of dark and light bands of interference. This activity also provided an opportunity for students to measure, in a crude sort of way, the wavelength of light.

The diffraction grating material activity is a much more accurate means of determining the wavelength of light than is the thin slits method but each is based on the same principle: that is, causing light to pass through closely ruled spaces. With the diffraction grating material the spaces are approximately 0.00019 cm apart. This very close spacing means that the student should be able to obtain a very close approximation to the wavelength of any color of the spectrum.

PROCEDURE

1. At the beginning of the activity, have students hold a mount of diffraction grating material -- ruled 5300 lines/cm (about 13,500 lines/inch) -- at arm's length and look through it at any available light source. Have them move the mount closer to their eye. Ask them what they observe? Do they see anything different when they look to the right or left side of the light source? Use another diffraction grating placed at right angles to the first. Ask what they see now? What happens when three or more gratings are used? During the activity, have the students observe a red, yellow, blue, or green light source. Does the color of the light source make a difference? Would the observations suggest a means to determine the purity of a light source?
2. Have the students set up the apparatus by placing a light source at the vertex of two meter sticks which have been placed at right angles to one another. Attach the diffraction grating material to the end of one of the meter sticks with tape or with a thumb tack. Position the meter stick with the diffraction grating to that the light can be viewed along this length. (See Fig. 8.) Two to four groups can use the same light source if the meter sticks are arranged properly. Look slightly to the left or right of the light source to locate the spectrum. Turn out the overhead lights and shield the view from other light sources in the room. You should see a spectrum on either side of the light and a secondary spectrum (n=2) further to the right or left of the first order spectrum. (In some instances, you may even be able to locate third (n=3) or fourth (n=4) order spectra.) Note that the blue line in the second spectrum on the left would be n=2 and the blue line in the second spectrum on the right would also be n=2.

   If you use colored filters, it is difficult to screen out unwanted light from the light source. I have used a tissue paper core which fits almost exactly over a showcase bulb. The open top presents no particular problem. Simply cut as many slits in the core as you need, wrap the filter around the core, and tape or use a rubber band to secure it in place. Cut one slit per group which will use the same light source. Place the tube over the showcase bulb and you are in business.

3. Again, the formula used to calculate the wavelength is an approximation* just as was the formula used in the thin slits activity. For our purposes we will use the same expression as was used before:

   $\lambda = (dy/nL)$ Where λ = wavelength
   d = grating spacing
   y = distance from the light source to the spectral line
   n = spectral line order
   L = distance from the diffraction grating material to the light source

This time we are using a known grating spacing of d = 1 cm/5300 lines or d = .00019 cm. This spacing is considerably closer than our lines made with the razor blades. The value "y" is obtained by measuring the distance from the center of the light source to the spectral line for which we are determining the wavelength. We will use the distance from the diffraction grating to the light source for the value of L. This is L = 100 cm. We can get a very close approximation to the desired wavelength by taking only one measurement, y.

*The actual formula is $\lambda = d \quad \sin\theta$, while we are using λ = distance θ. The values of the sine and tangent are very close when the angle θ is very small so the approximation is reasonable. You might check the closeness of the approximation by using the correct formula and the distance measured from the diffraction grating to the spectral line in question.

CONCLUSION

You may want to fill in all of the blanks in the formula except for the measurement that has to be taken. By substituting the known values, the formula becomes:

$$\lambda = (\quad d \quad)\ (y)/(n)\ (\ L\ )$$

$$\lambda = (0.00019\ \text{cm})\ (y)/(1)\ (100\ \text{cm})$$

$$\lambda = (0.0000019)\ (y)$$

For a first order spectrum (n=1), the measured value of "y" should range between 20 cm and 35 cm. For n=2 the value of "y" will be between 40 cm and 70 cm. The values for the wavelength should range from 0.000035 cm for violet to 0.000070 cm for red light regardless of the spectral order used.

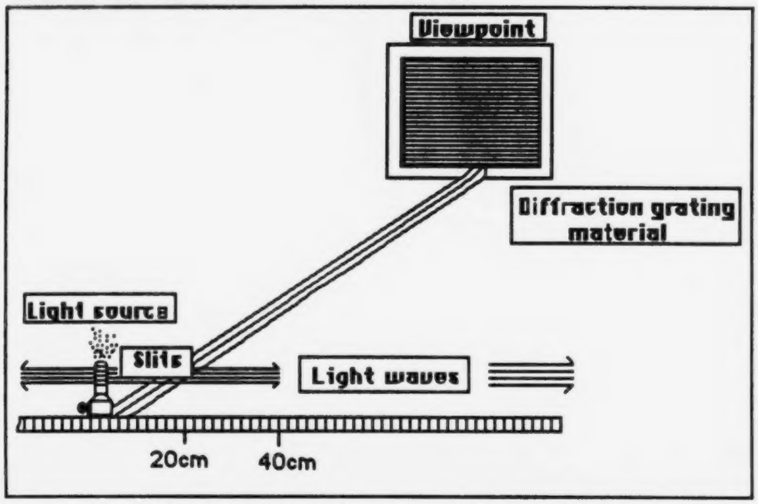
POSTLABORATORY DISCUSSION

This is nothing short of amazing! With something like fifty cents worth of diffraction grating and a couple of meter sticks, physical science students are able to make a measurement of 1/10,000 of a cm and to do something which the greatest scientists could not do less than a century ago! But the significance of this will be lost if your students are not aware of the application of these measurements in communications and research in the biological, chemical and physical sciences. Have them use the library to find applications of spectroscopy dealing with lasers, microchips, viral infections, genetics, industrial measurements, etc.

DETERMINING THE WAVELENGTH OF LIGHT

(Diffraction Grating Method)
Laboratory Exercise
--for the student--

DIFFRACTION GRATING METHOD



Diffraction method for determining the wave length of the different spectra of light.

PURPOSE

The purpose of this activity is to determine the wavelength of different colors of light. During the activity you will make measurements as small as one three hundred thousandths of a centimeter (0.00003 cm) by using a simplified version of a spectrometer. Workers in the chemical and electronic industries use a much more sophisticated version of the spectrometer to find the chemical composition of products in refineries and the purity of electronic chips which are used in computers, stereo component systems, and other electronic products. Astronomers also use this same technique to determine the composition of stars and other celestial bodies.

OBJECTIVES

When you have completed this activity you should be able to: (1) set up and conduct an experiment to determine the wavelength of any color of light in the visible spectrum and (2) measure the wavelength of any color of light in the visible spectrum.

MATERIALS (Per Group)

- Three meter sticks
- Diffraction grating material in a 35 mm mount
- Light source (preferably a showcase bulb)
- Transparent tape or one thumb tack
- Colored cellophane filters
- Tissue or paper towels

DISCUSSION

Have you ever watched the colored flames in a fireplace and wondered what makes the different colors, or watched a rainbow and wondered how the colors are separated?

Curiously enough it was regular people, not scientists, who first took advantage of the idea that the different colors of flames meant something. Ironworkers and blacksmiths observed that the flames in which metals were heated changed colors as the type of metal was changed. A copper flame was green, salt gave a yellow flame, and other metals gave off different colors. They also observed that the color of the metal changed as the flames became hotter and hotter. They found that the metals generally changed colors from yellow, to blue, to white as the temperatures became higher. The metals became easier to shape as the temperature increased and more importantly, the products had different physical properties when the metal was shaped at different temperatures.

As society became more and more specialized and the economic condition of the countries became more complex, so did the jobs which were available. Blacksmiths became metallurgists and metalworkers. Specialists were trained to study the properties of metals and how the addition of other materials could change the characteristics of the natural materials. This caused other specialists to be trained to recognize what impurities had been added to the naturally occurring metals. In the oil and chemical industries, people were also trained to recognize products by the color of the flame which was produced when materials were burned.

You can imagine the tremendous number of things which could be added to any material before it becomes a consumer product. Today, a plantworker may have the job of analyzing samples of a product to find the exact composition of the material. Other workers might have the job of finding out what new properties can be given to old materials if an additive is used.

PROCEDURE

1. Your materials include a clear looking material which is mounted in a 35 mm slide frame. Hold the material at arms length and look through it at a light source. Move the material closer to your eye. What do you see? Look slightly to the left of the light source through the material. Does this make a difference?

What do you see when you look to the left or right of the light source that you do not see when you look directly at the source? Record your observations in the space provided.

____

____

____

In this activity you will use the basic idea that white light can be broken down into the different colors of the spectrum and that the wavelength of these colors can be measured. The idea is that if you know the color, you can measure the wavelength of the light. In practice, if the worker can determine the wavelength of the light, the color -- and hence the kind of material -- can be determined.

2. Set up the apparatus as indicated in the above diagram by placing the light source at the vertex of two meter sticks which are placed at right angles to each other. Attach the diffraction grating material to the end of one of the meter sticks. Keep in mind that you are going to have to view the light source through the diffraction grating when you make your setup.

3. Look through the diffraction grating and locate the spectrum on the side where you have the other meter stick. Have your lab partner hold a pencil at the space over the meter stick where you see the blue line. How far is the blue line located from the light source? It should not be more than 40 cm nor less than 20 cm from the source. Practice locating other colors of the spectrum and measuring the distance from the light source. Again, all of your measurements should be between 20 and 40 cm from the source. Swap jobs. You measure and let your partner locate the spectral lines.

Complete this table:

COLOR	YOUR MEASUREMENT "Y"	PARTNER'S MEASUREMENT "Y"	AVERAGE "Y"
RED			
ORANGE			
YELLOW			
GREEN			
BLUE			

You have a direct measure which is taken from the meter stick. You have done the measure and have that measurement verified by your partner and although the numbers may not be the same, they are probably pretty close to each other.

4. You will now use your values to make an indirect measurement through the use of a formula. In your math classes you have learned to use ratio and proportion. We will use the same idea. If you look closely at the diffraction grating, you will see that there are many very fine lines on the material. In fact, there are 5300 lines/cm ruled on the film. Another way of saying this is that there occupies 0.00019 cm.

By doing a little manipulating of the relationships we can use the formula $\lambda = (dy/nL)$ to get an indirect measure of the wavelengths of the colors. Trust me, it works.

$\lambda = (dy/nL)$ where: λ = wavelength
d = grating spacing = (0.00019 lines/cm)
y = distance from the source to the color
n = spectral order of the color = (1)
L = distance from the grating to the light (100 cm)

When we fill out the formula it looks something like this:

$$\lambda = (\ d\ )\quad (y)\ /\ (n)\ (L)$$
$$\lambda = (0.00019\text{ cm})\ (y)/(1)\ \ (100\text{ cm})$$
$$\lambda = (0.0000019)\ (y)$$

Remember, you have to insert your value of "y" for the color for which you are determining the wavelength.

Complete the table:

COLOR	AVERAGE VALUE OF "Y" (From table above)	CALCULATED WAVELENGTH
RED		
ORANGE		
YELLOW		
GREEN		
BLUE		

This is amazing! You have just made a series of measurements which even the greatest scientists could not have made one hundred years ago. This is not "just another activity" to fill time between bells. Measurements just like these are made many times a day by workers in factories, laboratories, and hospitals. The equipment they use is much more sophisticated, but the ideas are the same. You can find out more about the topic by looking in the library for listings under spectroscopy, spectroscopes, spectral analysis, and topics related to color and spectra.

REFLECTION FROM PLANE SURFACES

Laboratory Exercise

--for the teacher--

PURPOSE

The purpose of this activity is to determine the angles of incidence and reflection in plane mirrors.

OBJECTIVES

The student will be able to:

1. Determine the angles of incidence and reflection of light on a plane mirror.
2. Describe the process by which images are located in plane mirrors.

MATERIALS

Plane mirror
Meter stick
Light source (flashlight or similar source)
Paper, pencil, straight pins and a piece of cardboard
Aluminum foil to cover flashlight lens

PRELABORATORY DISCUSSION

It turns out that Euclid worried about a lot of things, for in addition to plane geometry he also worked on geometric optics. (Keep in mind that he worried about these things around 300 B.C.) Of course, Plato and Aristotle also had their pet theories about how light behaved and around 200 A.D. Ptolemy stated what we now call the law of reflection. Basically, he stated that the angle of reflection is equal to the angle of incidence when each is measured to the normal, or perpendicular, to the reflecting surface. He also pointed out that the incident ray, the reflected ray, and the normal to the surface all lie in the same plane.

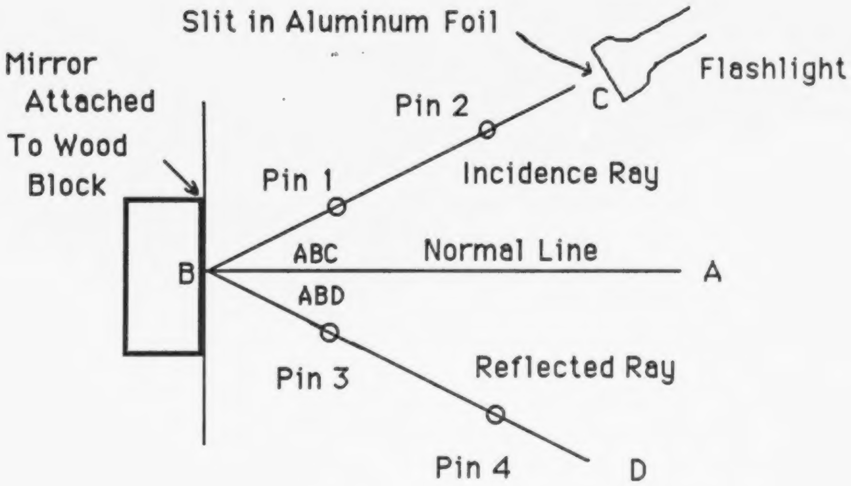
In addition, he clarified the meaning of "normal" to the surface in the case of curved mirrors. In curved mirrors it is the perpendicular to the tangent drawn to the curved surface. This bit of geometry is important since a tangent to a curve is also perpendicular to a radius of a curve. Thus, a ray drawn through the center of curvature will be reflected back on itself and this property can be used to check the accuracy of ray diagrams.

DISCUSSION

The simplest way to handle this as a demonstration is to cut a thin slit in a disk of aluminum foil and tape it over a flashlight which has a magnet on its side. Attach a magnet to a mirror and place both the mirror and the flashlight to a piece of sheet metal and draw a normal to the mirror at the point of incidence of the beam to the mirror. Both the incident ray and the reflected ray are visible for the whole class. You can measure the angles by using a protractor. If you don't want to hassle with the magnets, you can place the mirror and light on the surface of a lab table and trace the rays directly on the table top with chalk or use a piece of cardboard-backed paper to support the pins and trace the path with a pen to get a permanent record.

If the only purpose is to demonstrate that the angle of incidence is equal to the angle of reflection, this demonstration serves the purpose nicely. However, a built-in value of using a student lab is that it provides students with an opportunity to apply some of the geometry that they have learned. (You might also mention that the single lens reflex camera utilizes a pentaprism to capture images which are doubly reflected onto the film.)

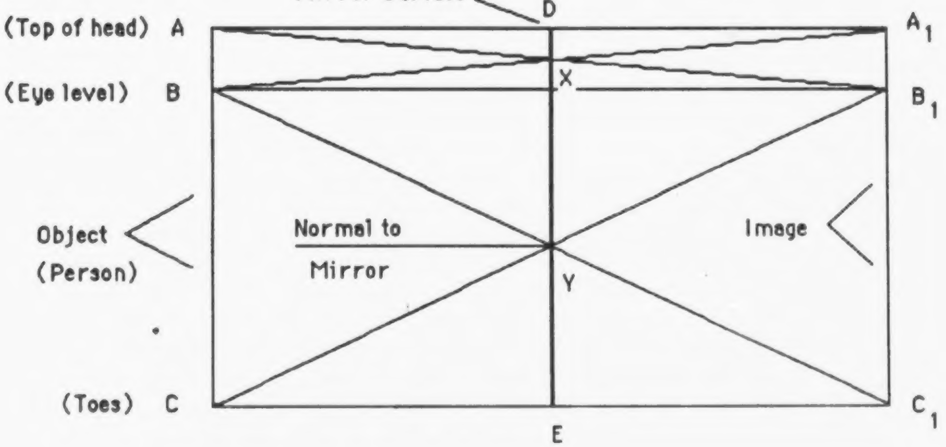
The student lab requires that students set up the apparatus in essentially the same way that you would for the demo. You might want to have the students align two straight pins in the incident beam and two pins in the reflected beam. This makes it easier for them to draw in the lines and measure the angles without having to work around the flashlight and mirror -- which usually get in the way and are disturbed during the measurements. The big problem that students will have is aligning the pin holes so that they intersect at point B.


Slit in Aluminum Foil
Flashlight
Mirror Attached To Wood Block
Pin 2
C
Pin 1
Incidence Ray
ABC
Normal Line
B
A
ABD
Pin 3
Reflected Ray
Pin 4
D

AB is drawn perpendicular to a line which is drawn along the edge of the mirror
Pins 1 and 2 are aligned in the incident ray
Pins 3 and 4 are aligned in the reflected ray
Lines are drawn through pin holes 1 and 2 and holes 3 and 4 to intersect at B
The angles of incidence and reflection are measured to line AB.

This is a good place to conclude the activity if the purpose is to show that the angle of incidence is equal to the angle of reflection. If you want to determine the extent to which the students understand the concept, you might ask them what would be the length of the shortest mirror in which they could view their entire length -- from the top of their head to the tip of their toes.

There are a number of good labs which demonstrate that an image is formed as far behing a plane mirror is the object is located in front of the mirror. You might just tell the students about this and then ask them to use that bit of information and the law of reflection to determine the length of the mirror mentioned above. As an alternative you could use a line drawing to generalize the process of finding the length of the required mirror.


Mirror Surface
D
(Top of head) A
A_1
X
(Eye level) B
B_1
Object
(Person)
Normal to
Mirror
Y
Image
(Toes) C
C_1
E

The line drawing might represent a person with the top of head at A; eye located at B; and the tip of the toes located at C. Point A1, B1, and C1 are located as far behing the surface of the mirror as A, B, and C are located in front of the mirror. The line of sight to the top of the head from eye level would be along the line BA1, while the line of sight to the tip of the toes would be along the line BC1. Reflection would occur at the surface of the mirrors are the lines "PX" and "MY". From the law of reflection, angle BXP is equal to angle PXA while angle BYM is equal to angle MYC. If you have accelerated students who are enrolled in geometry, you could pursue a rigorous geometric proof using congruent triangles. However, the simplest approach is to measure the distance XY, and compare it to the length of AC. Be sure that the students understand that the mirror parts XD and YE are not needed in order to view the image of the object.

PROCEDURE

1. Tape of fasten a ppiece of paper onto the flat surface of a section of cardboard. Put the paper/cardboard on a flat surface and mount the plane mirror vertically on the paper. (Use a rubber band and block of wood to stabilize the mirror if necessary.) Draw a line along the front edge of the mirror so you will know where to place the mirror again if it happens to move. This is called the reference line. Remove the mirror and draw a line perpendicular (a 90 degree angle) to the reference line. Mark the intersection of the perpendicular and the reference line as point B. Mark the other end of the perpendicular asa point A. Place the mirror back on the reference line.

2. Make a small straight slit (cut) in a section of aluminum foil and cover the lens of the flashlight with the foil. Check the foil to make sure that the slit is straight and very nearly centered over the flashlight lens. Hold the flashlight about 10 cm away from a sheet of paper to assure that only a straight thin beam of light is projected.

3. Place the flashlight on the paper and orient it so that the beam shines on point B. Stick two straight pins about 5 cm apart in the cardboard in the beam of light between the light and point B (pins 1 and 2.) Place two other pins in the beam reflected from point B (pins 3 and 4.) To check to see if the pins are properly aligned, you can look into the reflected beam. All four pins should appear to be in a straight line. In fact, if they are perfectly aligned, you should be able to see only one pin but that is not likely to be the case. The important part is that the points of the pins should all be in a row. If they are not, move the pin(s) which are out of alignment and get them straight. When you get them aligned, draw a small circle around the holes and number the holes 1, 2, 3, 4. Remove the pins, the mirror and the flashlight.

4. Draw a line through pin holes 1 and 2 and another line through pin holes 3 and 4. If you have done the work properly, the lines will intersect at point B. If the lines do not intersect you will have to go through the process again. Mark the end of the line where the flashlight was as point C and the end of the line where the beam was reflected as point D.

5. Measure angle ABC. Record this value. Measure the angle ABD. Record this value. Are they the same? If they are not, you will have to start over -- after all, the whole idea was to find out if you can show that the angle of incidence is equal to the angle of reflection.

6. Now it is problem solving time. What is the minimum length of a mirror that you can use to see your reflection from the top of your head to the tip of your toes? Hint: The image appears to be located as far behing a plane mirror as the object is in front of the mirror. Make a line drawing of an object, a mirror, and an image. Use this information and the law of reflection to find the length of the mirror required to see the object. Measure the length of the required mirror for the object. What relationship does the mirror length have to the length of the object? What relationship would exist between the required length of a mirror and your height?

REFLECTION FROM PLANE SURFACES

Laboratory Exercise
--for the student--

PURPOSE

The purpose of this activity is to determine the angles of incidence and reflection in plane mirrors.

OBJECTIVES

You should be able to:

1. Determine the angles of incidence and reflection of light on a plane mirror.
2. Describe the process by which images are located in plane mirrors.

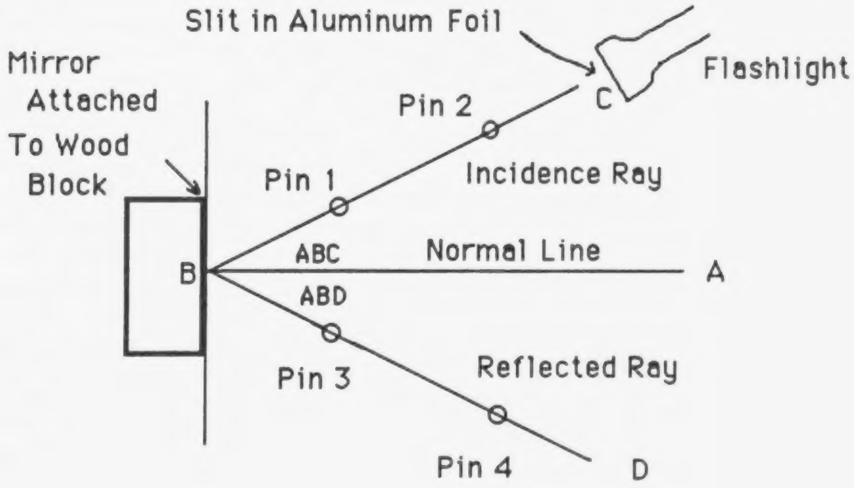
MATERIALS

Plane mirror and support
Meter stick
Light source (flashlight or similar source)
Paper, pencil, straight pins and a piece of cardboard
Aluminum foil to cover flashlight lens
Protractor

PRELABORATORY DISCUSSION

It turns out that Euclid worried about a lot of things, for in addition to plane geometry, he also worked on geometric optics. (Keep in mind that he worried about these things around 300 B.C.) Of course, Plato and Aristotle also had their pet theories about how light behaved and around 200 A.D. Ptolemy stated what we now call the law of reflection.

The law of reflection deals with how an incoming light beam, called the incident light, changes direction at a reflecting surface. It describes the relationship between the angle of incidence of light and the angle of reflection of light.


Slit in Aluminum Foil
Mirror Attached To Wood Block
Flashlight
Pin 2
C
Pin 1
Incidence Ray
ABC
Normal Line
B
A
ABD
Pin 3
Reflected Ray
Pin 4
D

PROCEDURE

1. Tape or fasten a piece of paper onto the flat surface of a section of cardboard. Put the paper/cardboard on a flat surface and mount the plane mirror vertically on the paper. (Use a rubber band and block of wood to stabilize the mirror if necessary.) Draw a line along the front edge of the mirror so you will know where to place the mirror again if it happens to move. Remove the mirror and draw a line perpendicular (a 90 degree angle) to the reference line. Mark the other end of the perpendicular as point A. Place the mirror back on the reference line.

2. Make a small straight slit (cut) in a section of aluminum foil and cover the lens of the flashlight with the foil. Check the foil to make sure that the slit is straight and very nearly centered over the flashlight lens. Hold the flashlight about 10 cm away from a sheet of paper to assure that only a straight thin beam of light is projected.

3. Place the flashlight on the paper and orient it so that the beam shines on point B. Stick two straight pins about 5 cm apart in the cardboard in the beam of light between the light and point B (pins 1 and 2.) Place two other pins in the beam reflected from point B (pins 3 and 4.) To check if the pins are properly aligned, you can look into the reflected beam. All four pins should appear to be in a straight line. In fact, if they are perfectly aligned, you should be able to see only one pin but that is not likely to be the case. The important part is that the points of the pins should all be in a row. If they are not, move the pin(s) which are out of alignment and get them straight. When you get them aligned, draw a small circle around the holes and number the holes 1, 2, 3, 4. Remove the pins, the mirror and the flashlight.

4. Draw a line through pin holes 1 and 2 and another line through pin holes 3 and 4. If you have done the work properly, the lines will intersect at point B. If the lines do not intersect you will have to go through the process again. Mark the end of the line where the flashlight was as point C and the end of the line where the beam was reflected as point D.

5. Measure angle ABC. Record this value. Measure the angle ABD. Record this value. Are they the same? if they are not, you will have to start over -- after all, the whole idea was to find out if you can show that the angle of incidence is equal to the angle of reflection.

6. Now it is problem solving time. What is the minimum length of a mirror that you can use to see your reflection from the top of your head to the tip of your toes? Hint: The image appears to be located as far behind a plane mirror as the object is in front of the mirror. Make a line drawing of an object, a mirror, and an image. Use this information and the law of reflection to find the length of the mirror required to see the object. Measure the length of the required mirror for the object. What relationship does the morror length have to the length of the object? What relationship would exist between the required length of a mirror and your height?

COLOR

Laboratory Exercise

--for the teacher--

PURPOSE

The purpose of this activity is to produce a spectrum and to investigate the effects of mixing the primary colors of light.

OBJECTIVES

The student should be able to:

1. Recall the colors of the spectrum in order from longest to shortest wavelength, and from shortest to longest wavelength.
2. Predict the resultant color from the mixing of any two of the primary colors of light.
3. Predict the appearance of various colored objects when they are viewed under different colors of light.

MATERIALS

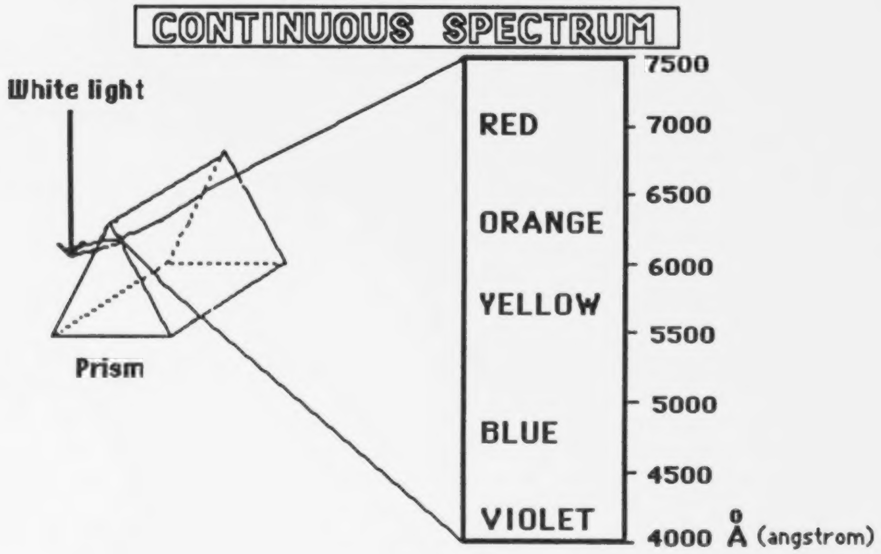
1. Equilateral or right angle prism and support
2. Flashlight and a larger source of light such as an overhead or slide projector
3. Assorted filters (red, green, blue, etc.)
4. Aluminum foil to cover the flashlight lens
5. Mirror tiles or assorted sized mirrors

DISCUSSION

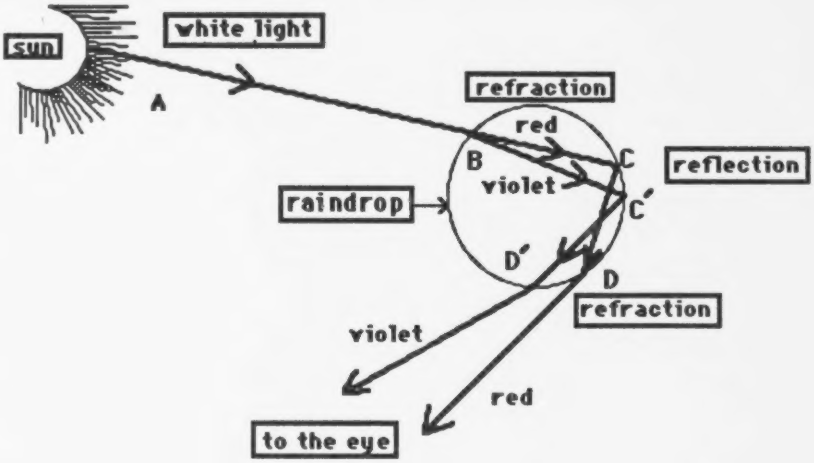
While Isaac Newton is generally credited with the first investigations of the spectrum, it would take a totally insensitive person to go through life without admiring the beauty of a rainbow, the glistening array of colors exhibited by a diamond, or the sparkling, dancing colors of a waterfall. Although Newton did not use the wave nature of light to explain the formation of the spectrum, it is important that he documented his demonstration that all of the colors of the spectrum could be produced from white light. In addition, he showed that the order of the colors of the spectrum was always the same. From our study of the wave nature of light, we know that red light has a long wave length, that violet light has a shorter wave length and that the other colors of the visible spectrum have wavelengths between these extremes.

It is these differences in wave length which cause the formation of the spectrum in the predictable order (from longest to shortest wavelength): Red, Orange, Yellow, Green, Blue, Indigo, and Violet. (ROY G. BIV is, of course, the famous mythical scientist who makes the spectrum work.) Make sure that the students know that the wavelength of red light is longer than the wavelength of violet light if you have them memorize the ROY G. BIV.

The spectrum produced by white light passing through a prism is essentially the same as the spectrum produced in a rainbow. In other instances, the light is separated into its component colors by the refraction of light. This separation of light into the component colors is called dispersion. In this demonstration experiment with a flashlight and a prism, the incident light passes through the prism. Violet light, having a shorter wavelength, is refracted most and will always appear on the side nearest the thicker (base) part of the prism. Red light, on the other hand, is refracted least and will be transmitted so that it appears on the side closer to the vertex of the prism. (See diagram.)


CONTINUOUS SPECTRUM
White light
Prism
RED
ORANGE
YELLOW
BLUE
VIOLET
7500
7000
6500
6000
5500
5000
4500
4000
Å (angstrom)

Spherical droplets of water in the air refract and reflect rays of sunlight to produce a rainbow. Again, since the violet is refracted more when it enters the droplets, it appears on top of the rainbow which is formed. (Remember the laws of incidence and reflection.) Red light, refracted less and reflected at a greater angle, appears at the bottom of the spectrum. (See diagram.)


sun
white light
A
refraction
red
B
C
reflection
violet
raindrop
C'
D'
D
refraction
violet
red
to the eye

While your are demonstrating/experimenting with the formation of the spectrum, it is a good time to introduce the idea of convergence and divergence of light rays by using two prisms.

Placed base to base, the prisms will act as a convex lens and will converge the light while the prisms placed vertex to vertex will diverge the light ray. This makes an excellent introduction to lenses, especially if you ask questions about the path of the rays or if you point out that the emerging light is either concentrated (converged) or dissipated (diverged.) (The diverged ray will show violet light at both the top and bottom of the beam while the converged ray will show the red light at the top and bottom of the beam.)

It is also possible to check the purity of color filters by observing the spectrum produced by light which passes through the filters. The presence of other colors will show how impure your filters really are. A red filter blocks out all the other colors of white light and transmits only red. Similarly, blue filters allow only blue light to pass and green filters allow only green light to be transmitted. The RGB color monitors used with computers are able to produce the whole range of the spectrum by combining red (R), green (G), and blue (B). Red, green and blue are known as the primary colors for light. Fair success in mixing the primary colors can be obtained by using three mirror tiles which have been covered with cellophane.

Cover one plane mirror tile with two or three layers of green cellophane, a second mirror with 2-3 layers of blue cellophane and a third mirror with 2-3 layers of red. (You can usually get the cellophane from the biology teachers -- they use it in some sort of plant growing experiment.) Shine a beam of light from an overhead or slide projector onto the covered mirrors and reflect the beams onto a screen or the white ceiling tiles. The overlapped reflections of the red and yellow light produce magenta while red and green produce yellow. A combination of the green and blue produce a light blue-green color called cyan. The combination of all three of the primary colors for light, red, green, and blue, will produce white light if sunlight is used. Reasonably good results will be obtained by using an overhead or slide projector light but expect the results to be less than pure unless the room is very dark. Student results with the flashlights will range from excellent to disappointing because of the variation of battery strength, ambient light, and incidental light from lab groups near them.

When colored items are selected to observe under the different colors of light, make sure that the color of the object is uniform. Construction paper especially will sometimes have white fibers embedded within the surface and will cause the color reflected to appear when it is not supposed to be reflected. Uniformly dyed dull cloth surfaces seem to be best for the activity.

The primary colors for light are not the same as the primary colors for pigments which the students have learned in their art classes. The primary colors for pigments are red, yellow, and blue. Selective mixing of these primary colors for pigments allows the artist to produce pigments of the secondary colors -- orange, green, and purple as well as any of the pastel colors. A good way to demonstrate this is to mix equal parts of powdered yellow and blue tempra paint (or finely powdered chalk) to produce green. By way of explanation, yellow tempra reflects yellow strongly and orange and green moderately. It absorbs the red, blue and violet light. The blue tempra reflects blue strongly and green and violet moderately while absorbing red, orange, and yellow. Thus, red, orange, yellow, blue, and violet are all absorbed while green is reflected moderately by both the yellow and blue tempra. Therefore the mixture is green because only the green is reflected.

PROCEDURE, Part I: (Forming a spectrum.)

Cover the lens of a flashlight with a piece of aluminum foil in which a slit has been cut. Place a prism vertically on a book or other support and direct the beam from the flashlight toward the prism. Use a white piece of cardboard or paper for a screen and project the spectrum onto the screen. Mark the location of the various colors of the spectrum on the screen. Which color is produced nearest the widest part (base) of the prism? Which color is produced nearest the vertex (pointed part) of the prism? Make a sketch of the experimental arrangement and trace the path which the various colors of light must take from the time the ray enters the prism to the formation of the spectrum on the screen. (Orient your sketch such that you are viewing the apparatus from above.) Which portion of the spectrum is bent most as it travels from the source to the screen? Which portion of the spectrum is bent least?

Recall (or consult your records) from your experiments with the diffraction grating materials which of these colors has the shortest and the longest wavelength. Which has the shortest wavelength? Which has the longest wavelength? Look at the paths of the colors which you have sketched. Which color was bent most? Which color path is bent least? From your observations, would you conclude that longer wavelengths are bent more or less than shorter wavelengths? Look at the location of the green and orange spectrum. Which has the longer wavelength?

The first letters of the names of the colors of the spectrum are sometimes arranged to make the name of a mythical scientist who keeps the colors of the spectrum in place. The letters from Red, Orange, Yellow, Green, Blue, Indigo, and Violet can be used to spell out the name of Roy G. Biv. Is the order of the colors represented by the letters given from longest to shortest wavelength or from shortest to longest wavelength? Write the names of the colors, in order, from shortest to longest wavelength.

Arrange two prisms, vertex to vertex, and shine a beam of light through both. How does the emerging beam behave? What colors are at the extremes of the spectrum on both sides? Now place the prisms, base to base, and shine a beam of light through them. What happens to these merging beams? What colors are on the extremes of the spectrum on both sides?

PROCEDURE, Part II: (Combining the primary colors for light.)

Hold a red filter in front of the flashlight. What color of light passes through the filter? What color of light passes through a green filter? A blue filter? What does the filter do with the other colors of light?

Cover one mirror with two or three layers of green cellophane, a second mirror with 2-3 layers of blue cellophane, and a third mirror with 2-3 layers of red cellophane. Make the surfaces as smooth as possible so that the light can be reflected evenly when the mirrors are used. Hold the filter covered mirrors in front of a light source and shine the reflected light onto a screen. What color is reflected by the red colored filter? What color is reflected by the green filter? The blue filter?

Reflect the light from the red and green mirrors onto the screen at the same time. Overlap the reflections. What color is produced when the red and green light is mixed? (Since your room is probably not completely dark and others are working in the room you may have to look very carefully at the surface to see the predominant color.) What color is produced when the red and blue light is mixed? What color does the combination of blue and green make? What color does the combination of blue and green make? Combine the colors from all three -- the red, green, and blue. What color is produced? These colors, red, green and blue, are the additive primary colors for light. The colors produced by the overlap of the additive primary colors are called the subtractive primary colors for light. What are the names given to the these primaries?

PROCEDURE, Part III: (The colors of objects.)

Hold a piece of red construction paper or cloth in front of the light reflected from the red cellophane covered mirror. What color does the material appear to be? Hold the red material in front of the blue reflected light. Does the color appear to change? If so, what color does it appear to be? What color does a green object appear to be when it is held in red light? Green light? Blue light? Observe a yellow object in the red light and then in green light. Note the differences. Then hold the yellow object in a mixture of the red and green light. What happens?

SUMMARY

1. Name the colors of the visible spectrum in order from shortest to longest wavelength.
2. What color would result from the mixing of red and green light? What is the resultant of mixing red, green, and blue light?
3. What color would a red object appear to be when placed under white light? Under blue light?

COLOR

Laboratory Exercise

--for the student--

PURPOSE

The purpose of this activity is to produce a spectrum and to investigate the effects of mixing the primary colors of light.

OBJECTIVES

At the conclusion of this lab you should be able to:

1. Recall the colors of the spectrum in order from longest to shortest wavelength, and from shortest to longest wavelength.
2. Predict the resultant color from the mixing of any two of the primary colors of light.
3. Predict the appearance of various colored objects when they are viewed under different colors of light.

MATERIALS

Equilateral or right angle prism and support
Flashlight and a larger source of light such as an overhead or slide projector
Assorted filters (red, green, blue, etc.)
Aluminum foil to cover the flashlight lens
Mirror tiles or assorted sized mirrors

DISCUSSION

While Isaac Newton is generally credited with the first investigations of the spectrum, it would take a totally insensitive person to go through life without admiring the beauty of a rainbow, the glistening array of colors exhibited by a diamond, or the sparkling, dancing colors of a waterfall. Although Newton did not use the wave nature of light to explain the formation of the spectru, it is important that he documented his demonstration that all of the colors of the spectrum could be produced from white light. In addition, he showed that the order of the colors of the spectrum was always the same.

The spectrum produced by white light passing through a prism is essentially the same as the spectrum produced in a rainbow. In both instances, the light is separated into its component colors by the refraction of light. This separation of light into the component colors is called dispersion. However, the formation of a rainbow involves reflection as well as dispersion within the water droplet.

PROCEDURE, Part I: (Forming a spectrum.)

Cover the lens of a flashlight with a piece of aluminum foil in which a slit has been cut. Place a prism vertically on a book or other support and direct the beam from the flashlight toward the prism. Use a white pipece of cardboard or paper for a screen and project the spectrum onto the screen. Mark the location of the various colors of the spectrum on the screen. Which color is produced nearest the widest part (base) of the prism? Which color is produced nearest the vertex (pointed part) of the prism? Make a sketch of the experimental arrangement and trace the path which the various colors of light must take from the time the ray enters the prism to the formation of the spectrum on the screen. (Orient your sketch such that you are viewing the apparatus from above.) Which portion of the spectrum is bent most as it travels from the source to the screen? Which portion of the spectrum is bent least?

Recall (or consult yuor records) from your experiments with the diffraction grating materials which of these colors have the shortest and the longest wavelength. Which has the shortest wavelength? Which has the longest wavelength? Look at the paths of the colors which you have sketched. Which color was bent most? Which color path is bent least? From your observations, would you conclude that longer wavelengths are bent more or less than shorter wavelengths? Look at the location of the green and orange spectrum. Which has the longer wavelength?

The first letters of the names of the colors of the spectrum are sometimes aranged to make the name of a mythical scientist who keeps the colors of the spectrum in place. The letters from Red, Orange, Yellow, Green, Blue, Indigo, and Violet can be used to spell out the name of Roy G. Biv. Is the order of the colors represented by the letters given from longest to shortest wavelength or from shortest to longest wavelength? Write the names of the colors, in order, from shortest to longest wavelength.

Arrange two prisms, vertex to vertex, and shine a beam of light through botyh. How does the emerging beam behave? What colors are at the extremes of the spectrum on both sides? Now place the prisms, base to base, and shine a beam of light through them. What happens to the emerging beams? What colors are on the extremes of the spectrum on both sides?

PROCEDURE, part II: (Combining the primary colors for light.)

Hold a red filter in front of the flashlight. What color of light passes through the filter? What color of light passes through a green filter? A blue filter? What does the filter do with the other of light?

Cover one mirror with two or three layers of green cellophane, a second mirror with 2-3 layers of blue cellophane, and a third mirror with 2-3 layers of red cellophane. Make the surfaces as smooth as possible so that the light can be reflected evenly when the mirrors are used. Hold the filter covered mirrors in front of a light source and shine the reflected light onto a screen. What color is reflected by the green filter? The blue filter?

Reflect the light from the red and green mirrors onto the screen at the same time. Overlap the reflections. What color is produced when the red and green light is mixed? (Since your room is probably not completely dark and others are working in the room you may have to look very carefully at the surface to see the predominant color.) What color is produced when the red and blue light is mixed? What color does the combination of blue and green make? Combine the colors from all three -- the red, green, and blue. What color is produced? These colors, red, green and blue, are the additive priamary colors for light. The colors produced by the overlap of any two of the additive primary colors are called the subtarctive pirmary colors for light. What are the names given to the these primaries?

PROCEDURE, Part III: (The colors of objects.)

Hold a pipece of red construction paper or cloth in front of the light reflected from the red covered mirror. What color does the material appear to be? Hold the red material in front of the blue reflected light. Does the color appear to change? If so, what color does it appear to be? What color does a green object appear to be when it is held in red light? Green light? Blue light? Observe a yellow object in the red light and then in green light. Note the differences. Then hold the yellow object in a mixture of the red and green light. What happens?

SUMMARY

1. Name the colors of the visible spectrum in order from shortest to longest wavelength.
2. What color would result from the mixing of red and green light? What is the resultant of mixing red, green, and blue light?
3. What color would a red object appear to be when placed under white light? Under blue light?

Sound and Music 14

Background Information

Sound is the sensation of hearing, which is a result of mechanical vibrations set up in solids, liquids, and gases. Sound is an elastic compressional wave. It is similar to light in that both are vibrations. Light, however, is an electrical vibration which consists of electric and magnetic fields. It can travel in a vacuum and does not need a medium. Sound requires a medium.

Few topics are as interesting to study as sound. Sound relates to sensations that improve the quality of life. Speech and music are two aspects of life which we would have great difficulty getting along without. The next time you watch television, turn off the sound and determine how long you desire to watch the tube without the sensation of hearing. Can you imagine life without music?

PROPERTIES THAT AFFECT SOUND

Sound requires matter to travel in, and the properties of this matter relate to the speed and quality of this transmission. Two important properties to consider are **density** and **elasticity.** Density relates to sound transmission. Note on the chart that as the density of a substance increases, often the speed of the sound in it increases. For example, note that the speed of sound through air, water, aluminum, and steel increases much as their densities increase. However, there are some exceptions to this generalization. Lead is much denser than aluminum, but sound travels slower in it than in aluminum. This can be explained by considering another factor that contributes greatly to the transmission of sound--elasticity.

SPEED OF SOUND IN SUBSTANCES
OF DIFFERENT DENSITIES

SUBSTANCE	DENSITY gm/cm^3	SPEED m/sec
Air at 20° C	0.0012	343
Cork	0.22 to 0.26	500
Wood (oak)	0.60 to 0.90	3850
Water 25° C	0.92	1498
Brick	1.4 to 2.2	3650
Aluminum	2.7020	5000
Steel	7.8800	5200
Nickel	8.9000	4900
Lead	11.3400	1210

Sound travels faster through materials that are more elastic. This is evidenced by the speed of sound through steel and oak wood as compared to lead. Steel rods and oak boards have a great deal of spring in them, unlike a rod of lead, which when bent, does not return to its original position or shape. The elasticity or stiffness causes an object to return to its initial form after being stretched or bent. Rubber bands are said to be elastic because they return to their original length after they are stretched. Similarly, heavy steel springs used in automobiles attempt to keep their bodies level at a given height off the ground when compressed or stretched due to passengers and bodies level at a given height off the ground when compressed or stretched due to passengers and bumps in the road.

Density or inertia opposes the motion of a stretched or bent material. Materials that possess a great deal of mass may have a great deal of inertia. The inertial property of a medium reduces its ability to transmit sound because its matter resists movement and vibration. The relationship between elasticity and inertia is given in an equation that states the speed (v) of sound is proportional to the square root of the elasticity of the medium, divided by the inertia of the medium:

$$v \propto \sqrt{\frac{\text{elasticity}}{\text{inertia}}}$$

When you analyze this equation, you can explain why sound travels slower in lead than in steel (see the table above). Lead is not very elastic, but it is very dense and possesses much mass. Consequently, the numerator is small and the denominator large when you consider the speed of sound in lead. Steel differs from lead. Steel is very elastic, which is why automobile and watch springs are made of steel. However, steel is less dense than lead, so the numerator of the equation is relatively larger and the denominator smaller when you calculate the speed for sound in steel versus lead. You will also note that thicker strings vibrate slower and have a lower pitch than thinner strings.

Place the table from the preceding page and the equation shown above on the chalkboard. Call on many students to reason and explain why the speed of sound in a given medium is great or small, considering the properties of elasticity and inertia. This discussion will help students explain why some phones transmit sound better than others when they participate in the "string telephone" laboratory exercise. Do not tip them off to the explanations related to this lab--that would spoil a great inquiry session.

SOUND WAVES

Perhaps a discussion of sound waves will provide a better understanding of sound's properties and characteristics. When an object is alternately compressed and stretched, the atoms that form it move back and forth in a certain pattern. During this motion, the atoms are compressed closer together and then stretched farther apart. This causes a **compression** which crowds the atoms together and a **rarefaction** which allows the atoms to be farther apart.

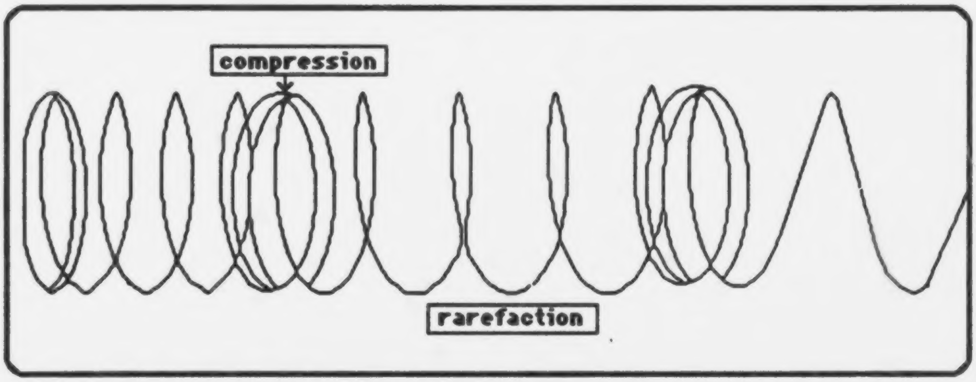
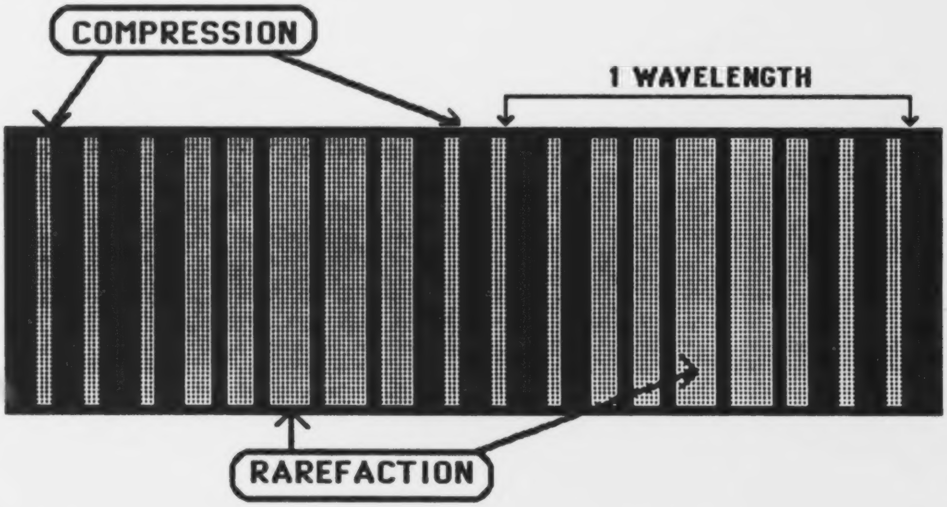


Diagram: Illustration of rarefaction and compression along a spring.

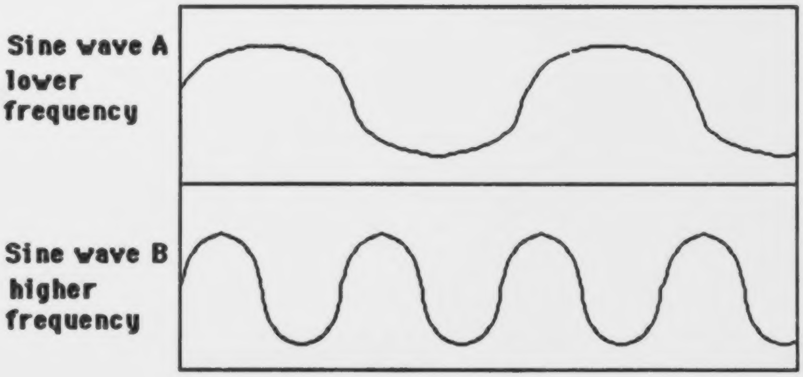
You can illustrate this compression and rarefaction in matter with a spring. Vibrate a spring such as a slinky and observe the coil moving back and forth; note there are intervals of dense and less dense coils in the spring. The same thing happens to the air molecules that are set into motion by the surface of vibrating objects.

Note in the figure above the areas of compression and rarefaction, and imagine the air molecules of the resulting sound wave striking an object such as your ear drum, which is set into motion with a pattern similar to that of the wave. This type of disturbance in matter is known as a **longitudinal** wave because molecules of matter vibrate back and forth along the path of the wave motion. Remember, however, that this disturbance which accompanies sound emanates in all directions away from its origin if a medium is present.

Sound waves are similar in some respects to the waves produced when you drop a pebble into a pond. The resulting disturbance causes a wave path which radiates 360 degrees from the point where the pebble hit the water. However, sound waves are different than water waves because they radiate in all directions, not just in one plane. Furthermore, they are longitudinal waves, which vibrate back and forth. Water waves are transverse waves, which vibrate up and down along the path they travel. Just as a light wave has a certain frequency, a sound wave has one also. **Frequency** is the number of vibrations or waves per unit time that pass a certain point. For a sound wave, it is the number of compressions that impact a given point during a second. Obviously, objects that vibrate rapidly produce many more compressions and rarefactions than objects which vibrate at a slower rate.



Scientists, engineers, and mathematicians frequently use sine waves to illustrate the characteristics of sound waves. Sine waves are easy to draw and to use for analyzing physical phenomena. In the sine wave below, "B" has a higher frequency than "A".



Sine waves with differing frequencies.

The frequency of a sound wave is expressed in hertz (Hz). If, for example, a sound wave produces 25 compressions and rarefactions per second, the frequency would be considered to be 25 Hz. The human auditory system is sensitive to a range of frequencies from approximately 15 to 20,000 Hz. Frequencies of less than 15 Hz are said to be in the infrasonic region, those between 15 to 20,000 Hz are in the sonic region, while those above 20,000 Hz are said to be in the ultrasonic region of sound.

Infrasonic Region	Sonic Region	Ultrasonic Region
Below 15 Hz	Between 15 and 20,000 Hz	Above 20,000 Hz

Musical instruments produce fundamental sounds between 20 and 5000 Hz. The lowest note on the piano is A_0 which is 27.5 Hz, while the highest note is C_8 which is 4,186 Hz. Perhaps you can now realize why it is necessary to have good stereo equipment if you wish to produce music which is perceptible in the lowest range of the human auditory system. You will have to purchase a good set of speakers in order to get woofers that will produce clean sounds in the 30 to 40 Hz range, and you may have to get a subwoofer to produce "good sounds" in the 20 to 30 Hz range.

Even though our ears are very sensitive to minute vibrations of air molecules, it is only when these vibrations occur in rapid succession that we perceive them. A sound wave or a longitudinal wave disturbance must vibrate at least 20 times per second before it is perceived by the human auditory system. If these vibrations are too rapid, they will not be perceived, such as vibrations that are over 20,000 Hz.

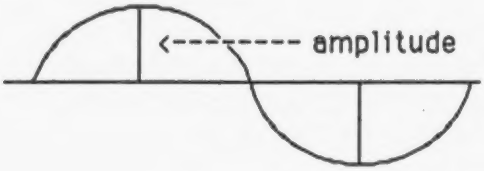
Your ears are most sensitive to vibrations in the frequency range between about 1000 and 4000 Hz. Changes in atmospheric pressure about one part in ten billion, if repeated about 3500 times a second, will send an audible sound to your brain. At this minute pressure variation, the eardrum moves less than one hundred thousandths of the wave length of light, one tenth the diameter of the smallest atom. If your ears were very much more sensitive, you would probably be able to hear the motion of the molecules of the air as they vibrated with thermal energy. (Folkways Records, 1959; p. 2)

Pitch is directly related to frequency, but, while frequency is a physical property of sound, pitch is a psychological phenomenon. It is a subjective experience of a periodic wave form. Pitch is how high or low sound appears; it denotes the shrillness of a sound.

Pitch is an integral part of music, and "We know that there is a certain regularity to music which relates to its pitch and periodicity. We know that the periodic nature of musical sounds arises from the nature of waves, in air and strings." (Pierce, 1983; p. 23) How then do you produce sound or music with a high or low pitch? There are two ways to alter the pitch of a sound made by a string or pipe. First, you can increase the length of a string so the wave has a longer distance to travel. Thus the string will vibrate slower, producing a low sound. Similarly if you increase the length of a tube or pipe, the air has a longer distance to travel and produces a lower sound. Second, you can make the string thicker and thus heavier by winding it with a material. This will give the string more mass and inertia, decreasing the speed of the vibrating string and the wave which travels across it. In a pipe you can use a different gas, by increasing the density of the gas you can lower the sound. In a vibrating string or a sounding organ pipe, the pitch is determined by the time it takes a transverse wave to travel back and forth along its length.

There is not a one-to-one correspondence between the frequency of a sound and the pitch we perceive. The pitch of an 880 Hz tone does not sound exactly twice as high as one at 440 Hz. Many individuals might judge a pure tone of 220 Hz to be one-half the pitch of a pure tone at 500 Hz. Although the one pitch sounds about one-half the other, it is not one-half its frequency. Therefore, pitch and frequency are not linearly proportional, and if you double the frequency you will not in general hear a tone that is perceived to be twice as high. Although pitch depends on frequency, it also varies with the loudness of the sound which relates to its amplitude. (Folkway Records, 1959; P. 3)

In addition to frequency, sound waves have another characteristic, which is **amplitude**. The amplitude of a wave is its intensity or its power. Specifically, the amplitude of a wave is its maximum displacement from its normal position. In the diagram below, the amplitude of the sine wave is the distance from the center line to the top of the wave. Just as an ocean water wave becomes more powerful as the wave height increases, a sound wave becomes more powerful and louder as its amplitude increases. If you pluck a guitar string with a large force, it will vibrate up and down, moving greater distance than if you pluck the string gently. Thus, sound waves that have a large amplitude move more air molecules as they move through space than sound waves with a small amplitude.



You must not confuse loudness with the intensity (amplitude) because intensity is an objective, physical characteristic of a sound. **Loudness** is a subjective, psychological impression; it is what the listener actually hears. Loudness depends on intensity and the frequency of the sound vibration. In other words, your ears judge loudness differently for different frequencies and intensity levels. Before we consider examples of this, let's review units of measurement which pertain to the loudness of sound.

The loudness for a sound is measured in a unit called the decibel. The symbol for decibel is db.

Intensities and Intensity Levels of Common Sounds

Source of Sound	Intensity (W/m^2)	Intensity Level (db)	Description
Large rocket engine (nearby)	10^{6}	180	
Jet takeoff (nearby)	10^{3}	150	
Rock concert with amplifier	1	120	Pain threshold
Subway train	10^{-2}	100	
Heavy truck engine (15m)	10^{-3}	90	Constant exposure endangers hearing
Vacuum cleaner	10^{-4}	80	
Normal conversation	10^{-6}	60	Quiet
Library	10^{-8}	40	
Rustling leaves	10^{-10}	20	
	10^{-12}	0	Hearing threshold

Note that the intensiy levels of sounds that we encounter most frequently are in the range between 10 and 70 decibels, which is a safe and comfortable situation for most of us. When we experience intensity levels above 90 db for long periods of time, a loss of hearing will begin to take place. In the range beyond 120 db, we will become uncomfortable, and at 120 db we will experience physical pain.

A word of caution is in order for students at this point in their study of sound. Teenagers have a tendency to play music loud: they seem to equate joy of listening with volume. Many turn up their stereo sets until the walls in their bedroom vibrate. You often "hear" youngsters listening to a radio or cassette player with a pair of head phones; I did say "hear" because you can hear the music coming out of the head phones. When you have this situation, you know the intensity level of the sound reaching the ear drum of the youngster is high. You know this child is doing some harm to his/her auditory system. No wonder we shake our heads in horror when we see some kid go by with a "ghetto blaster" booming away held up on the shoulder next to the ear.

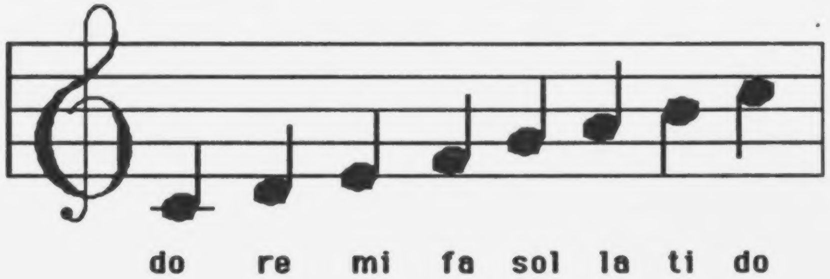
Governmental agencies have many regulations to protect workers in industry from excessive noise. For example, the U.S. Environmental Protection Agency recommends that workers be exposed to a maximum of 85 decibels for an eight hour day, and if the sound level is higher, the work time be decreased correspondingly. You will note that people who work on the landing field of airports wear protective ear covers. People in factories often wear these same protectors or place ear plugs into the external ear canal. These ear plugs are rated, some indicate that they reduce sound levels by 26 decibels. Hours of exposure to high levels of sound can produce temporary hearing loss. Years of exposure to intense sounds for several hours a day can produce a permanent loss of hearing called "boilermakers deafness". Momentary exposure to extremely loud noise, such as given off by an artillery gun a few feet away, can permanently injure the ear. (Stevens and Warshofsky, 1980)

We must not let ourselves believe that sound is just a problem of modern times, because even before the time of Christ people had ordinances for noise. "As far back as 720 B.C., the city of Sybaris, an outpost of Greek civilization in Italy, instituted a zoning system designed to isolate the industrial and residential sections of the town from each other. In the first century B.C., Julius Caesar issued an ordinance banning chariots from the streets of Rome during the night. (Stevens and Warshofsky, 1980; p. 174)

SOUND AND MUSIC

No study of sound would be complete unless it addressed some aspects of music. Music is distinguishable from noise in that it is characterized by rhythm and has certain patterns which repeat. If you listen closely to music you will notice periodic sound with variations in pitch. Consequently, music is composed of certain sounds which combine rhythmically.

In the study of music, pitch is still defined as how high a tone sounds, but there are opportunities to investigate this concept concretely through experience. The musical scale is used to graphically represent the notes and pitch of muscial tones. The words "do, re, me, fa, sol, la, ti, do" are common to most people. They communicate the pitch of sounds familiar to many people whether they are spoken, sung or played on an instrument.



Notes of varying pitch are accomplished in several ways when music is played on instruments. The objective, however, is always the same--change the speed of vibration which changes the pitch. As you tighten a string, it vibrates faster, increasing the pitch. As you lengthen a string or a sound pipe, you decrease the speed of vibration. As you thicken a string, it vibrates slower. Therefore, tightness, length, and thickness are three variables that are directly related to pitch and that students can manipulate to study sound and music.

Loudness is another subjective aspect of music that can be studied and appreciated through science. Earlier in this discussion, it was indicated that the decibel is a unit that signifies intensity level. The table below shows the relationship among levels of intensity in decibels and their musical equivalents. We bet you wondered what music teachers were trying to communicate when they used words like pianissimo and forte in their attempts to get musical groups to play softer or louder. The table below should clarify some of this mystery and reinforce the usefulness of the concept of the decibel in understanding loudness (Rigden, 1977; p. 32).

Loudness db	Italian Description		English Translation
90	fff	no Italian word	Extremely loud
80	ff	fortissimo	Very loud
70	f	forte	Loud
60	mf	mezzo forte	Moderately loud
50	p	piano	Soft
40	pp	pianissimo	Very soft
30	ppp	no Italian word	Extremely soft

Harmonics are the essence of music and pleasing sounds. Without harmonics, we would experience pure tones which are dull and uninteresting. Harmonics are the individual component tones that make up overall tones of a musical note. When you play middle C on the piano, you are hearing more than the pure frequency tone C with the pitch sound known as "do". There are many tones which combine to produce the "do" sound that you hear. For that matter most sounds are composites. The string which produces middle C on the piano not only vibrates as a whole, giving rise to a fundamental tone, but it also vibrates in smaller segments. These small vibrations occur in halves, thirds, fourths, and progressively in smaller segments, each of which produces proportionally higher pitches than the whole or fundamental vibration. So whether you pluck or strike a string or blow across a tube, you produce a complex sound wave made up of many harmonics, even though the resulting sound seems pure and simple to the untrained ear.

Timbre is a fundamental attribute of music that relates to harmonics. Timbre is the characteristic of a tone which depends on its harmonic structures. For example, if a musician plays the fundamental tone "A" on the piano and the violin, most people would be able to indicate which instrument produced this note. Even though the same note on each instrument produces a fundamental wave frequency of 440 Hz, each note has different harmonics associated with it, which are characteristic of the piano and the violin. Similarly, most people could distinguish the 440 Hz "A" note produced by the human voice from one produced by the guitar--they have different characteristics.

USING SOUND FOR "SEEING"

Sound is used for more than music and oral communication. Humans and animals use sound to "see" or determine what is in front of them. For example we all tend to listen carefully when we approach an intersection that we wish to cross. Our ears tell us if there are vehicles approaching and what type they might be; dump trucks have a rumble distinguishable from automobiles. Blind people use their cane to give them clues as to what is under and in front of them. Notice how they tap their cane as they walk about. The sound produced from this tapping indicates whether the person is on the sidewalk or on the grass. It can also indicate whether they are approaching an open area or a wall by the sound that is reflected back from the sound sent out by the cane striking the ground.

Echolocation is used by several animals to find their way at night and to hunt for food. The porpoise has a highly developed echolocation system for navigating in the dark murky waters of the ocean. Although they have good eyes, porpoises lack the sense of smell but make up for this deficiency with an extraordinary sound locating system. The porpoise emits high frequency sounds around 150,000 Hz which enables it to navigate around a maze of objects in dark waters with astounding skill. Scientists are puzzled at this because the porpoise has no vocal cords, and no one knows how they make the ultrasonic sounds they use for finding their way or the mewing or whistling noises they apparently use to communicate with other porpoises (Stevens and Warshofsky, 1980).

Bats are equally as amazing as porpoises in getting around in the dark and plucking their food out of the air. They emit pulsating beeps at frequencies ranging from 20,000 to 120,000 Hz. Their echolocation system is so finely tuned that bats can locate an object that projects 1/16 of an inch out of water. They can zip around twigs and catch moths or other elusive flying insects with amazing accuracy. Some species of bats have been credited with 500 kills an hour (Stevens and Warhofsky, 1980; p. 140).

REFERENCES AND SUGGESTED READINGS

Folkway Records. (1959) The Science of Sound (LP FX 6007). Produced by Bell Telephone Laboratories and distributed by Folkway Records, 623 Broadway, New York, N Y. 10012. This is a two album set of records with a carefully narrated presentation of sounds of all types. Its approximate cost is $20.

Pierce, John R. (1983) The Science of Musical Sound. A Scientific American Library book, distributed by W.H. Freeman and Co., N. Y.

Rigden, John S. (1977) Physics and the Sound of Music. John Wiley & Sons, N.Y.

Scientific American, Inc. (1978) The Physics of Sound. W.H. Freeman and Co., San Francisco. This is a collection of eight eassys on sound and music produced on various instruments.

Stevens, S. S. and Warshofsky, Fred. (1980) Sound and Hearing. Life Science Library, Time-Life Books, N.Y. This is a book that all science teachers should have on their shelf.

AND NOW .... THE HIGH LOWS

Paper and Pencil Exercise

--for the teacher--

Let's reinforce our knowledge of frequency and pitch. These two concepts help us to identify sounds and appreciate the quality of music. Respond to the questions below using complete sentences and good grammar.

1. What is the frequency of a sound wave?

Answer -- The frequency of a sound wave is how fast it vibrates per second.

2. What units are used to indicate the frequency of a sound wave?

Answer -- The units used to indicate the frequency of a wave are Hertz (Hz).

3. What dimension of a sine wave determines the frequency of the wave?

Answer -- The frequency of a sine wave is determined by the distance between peaks or crests on the wave.

4. What dimension of a compression wave determines the frequency of the wave?

Answer -- The frequency of a compression wave is determined by the distance between intervals of compression on the wave.

5. What is the pitch of a tone?

Answer -- The pitch of a tone is how high or low it sounds.

6. Compare and contrast pitch and frequency.

Answer -- Pitch is related to frequency and as the frequency of a tone increases so does the pitch. Nevertheless, as the frequency of a tone doubles, it will not sound twice as high. Pitch is what you hear or perceive, while frequency is a physical property of a sound wave.

7. Name a few musical instruments that generally produce tones with a high pitch, and name a few that produce tones with a low pitch.

Answer -- violin and flute; tuba and bass drum.

8. Match the items in column B with the phrases in column A by writing the appropriate letters on the lines to the left of column A.

Column A

g The upper frequency limit of human hearing.
d The musical note designated as "C" on the scale.
f The psychological aspect of a tone we hear.
b Tighten a string.
c The speed of vibration.

Column B

a. lower pitch
b. raise pitch
c. frequency
d. do
e. la
f. pitch
g. 20,000 Hz
h. 40,000 Hz

AND NOW .... THE HIGH LOWS

Paper and Pencil Exercise

--for the student--

Let's reinforce our knowledge of frequency and pitch. These two concepts help us to identify sounds and appreciate the quality of music. Respond to the questions below using complete sentences and good grammar.

1. What is the frequency of a sound wave? ______________________________

   ____

2. What unit is used to indicate the frequency of a sound wave?

   ____

3. What dimension of a sine wave determines the frequency of the wave?

   ____

4. What dimension of a compression wave determines the frequency of the wave?

   ____

5. What is the pitch of a tone? ______________________________

   ____

6. Compare and contrast pitch and frequency. ______________________________

   ____

   ____

7. Name a few musical instruments that generally produce tones with a high pitch, and name a few that produce tones with a low pitch.

   ____

8. Match the items in column B with the phrases in column A by writing the appropriate letters on the lines to the left of column A.

Column A	Column B
___ The upper frequency limit of human hearing.	a. lower pitch
___ The musical note designated as "C" on the scale.	b. raise pitch
___ The psychological aspect of a tone we hear.	c. frequency
___ Tighten a string.	d. do
___ The speed of vibration.	e. la
	f. pitch
	g. 20,000 Hz
	h. 40,000 Hz

"TURN IT DOWN, I CAN'T HEAR!"

Paper and Pencil Exercise

--for the teacher-

We have all heard the phrase: "Turn it down, I can't hear!" This is a statement frequently uttered by parents to their youngsters when perhaps the TV or stereo is turned up too high. Teenagers have a great deal of experience with the intensity of sound and how to control this variable. Therefore, they should do well in completing the sentences below which relate to this aspect of science.

1. The amplitude of a sound wave is related to its loudness.
2. The dimension of a sine wave that determines its amplitude is the height of its crest.
3. Pitch is to frequency as loudness is to amplitude.
4. Intensity level or loudness is measured in a unit called the decibel.
5. The intensity level of rustling leaves is 20 decibels.
6. The intensity level of normal conversation is 60 decibels.
7. The intensity level of a heavy truck engine is 90 decibels.
8. The intensity level of a rock concert with amplifiers is 120 decibels.
9. At what intensity level would constant exposure to a sound begin to endanger your hearing? 90 decibels
10. When the conductor of an orchestra says "piano" to the musicians, what intensity level is he/she referring to? 50 decibels

"TURN IT DOWN, I CAN'T HEAR!"

Paper and Pencil Exercise
--for the student--

We have all heard the phrase: "Turn it down, I can't hear!" This is a statement frequently uttered by parents to their youngsters when perhaps the TV or stereo is turned up too high. Teenagers have a great deal of experience with the intensity of sound and how to control this variable. Therefore, you should do well in completing the sentences below which relate to this aspect of science.

1. The amplitude of a sound wave is related to its ________________________.

2. The dimension of a sine wave that determines its amplitude is the

   ____________________________________.

3. Pitch is to frequency as ____________________________ is to amplitude.

4. Intensity level or loudness is measured in units called ____________________________.

5. The intensity level of rustling leaves is ____________________________.

6. The intensity level of normal conversation is ________________________________.

7. The intensity level of a heavy truck engine is ________________________________.

8. The intensity level of a rock concert with amplifiers is ____________________________.

9. At what intensity level would constant exposure to a sound begin to endanger your hearing?

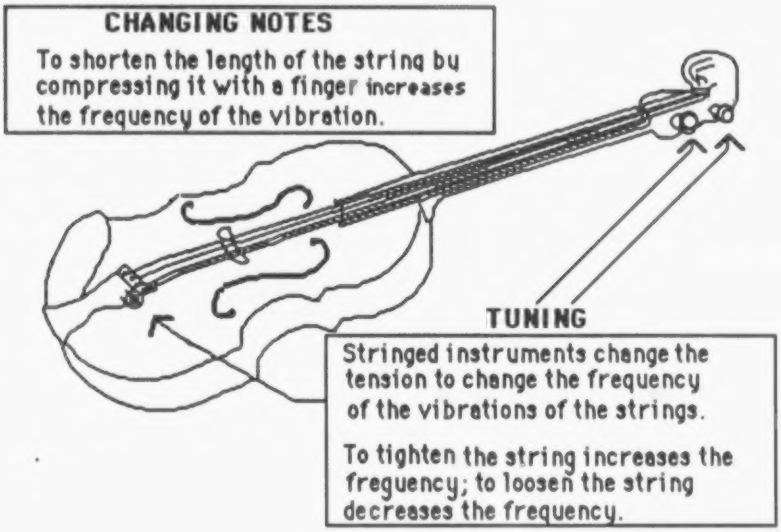
   ____

10. When the conductor of an orchestra says "piano" to the musicians, what intensity level is he/she referring to?

    ____

SOUND VIBRATION

Demonstration



CHANGING NOTES

To shorten the length of the string by compressing it with a finger increases the frequency of the vibration.

TUNING

Stringed instruments change the tension to change the frequency of the vibrations of the strings.

To tighten the string increases the frequency; to loosen the string decreases the frequency.

PURPOSE

Vibration is one of the main concepts to emphasize when introducing sound. This idea should be brought out as frequently as possible. However, ask questions that will cause students to observe mechanical vibrations that produce sounds, and to explain how this motion produces stimuli that can be detected by the sense of touch and hearing. The short demonstrations which are suggested below are an excellent way to increase student attention and interest during classroom discussions. Furthermore, the demonstration/discussion approach will help youngsters understand and explain the production and transmission of sound.

MATERIALS

ruler
cigar box or cardboard box or wooden box (approx. 6 x 9 inches)
several rubber bands of different thickness
guitar or other string instrument
tuning fork

PROCEDURE

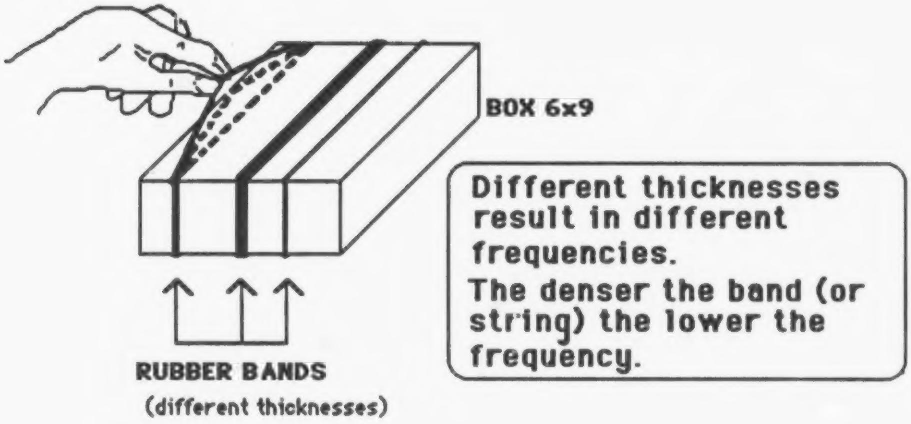
1. Ruler

Hold a ruler on your demonstration table so it hangs over the edge. Hold the end of the ruler tightly on the table top and snap the free end to vibrate. Note as you change the length of the free end that extends over the table, the frequency and pitch of the vibrating ruler changes.

Assemble the students so they can see what is taking place. Call on a few students to demonstrate how to vary the pitch of the sound emitted from the vibrating ruler. Some lead questions:

Can you see the vibrations?
Can you feel the vibrations?
Can you hear the vibrations?
How can you increase the pitch of the sound produced by the ruler?
Why does the pitch increase as you decrease the length of the vibrating part of the ruler?

Answers -- As you decrease the length of a vibrating object such as the ruler, or string, or column of air, you increase the speed at which it moves back and forth. Speed of vibration accounts for the pitch of the buzzing sound that is emitted. A humming bird's wings move up and down much faster than those of an eagle, and hence produces a higher pitch sound.



Different thicknesses result in different frequencies.
The denser the band (or string) the lower the frequency.

2. Rubber Band Stretched Over A Box

Select three or four rubber bands of equal length but of different thickness. Stretch the bands around the box. It is best to use a combination of box and band size that causes the rubber bands to be stretched tightly around the box because this produces the clearest sounds.
Call on a student to pluck each rubber band and note the pitch of the sound. Record the pitches on the chalkboard.

Why do the skinniest bands produce the highest pitches?

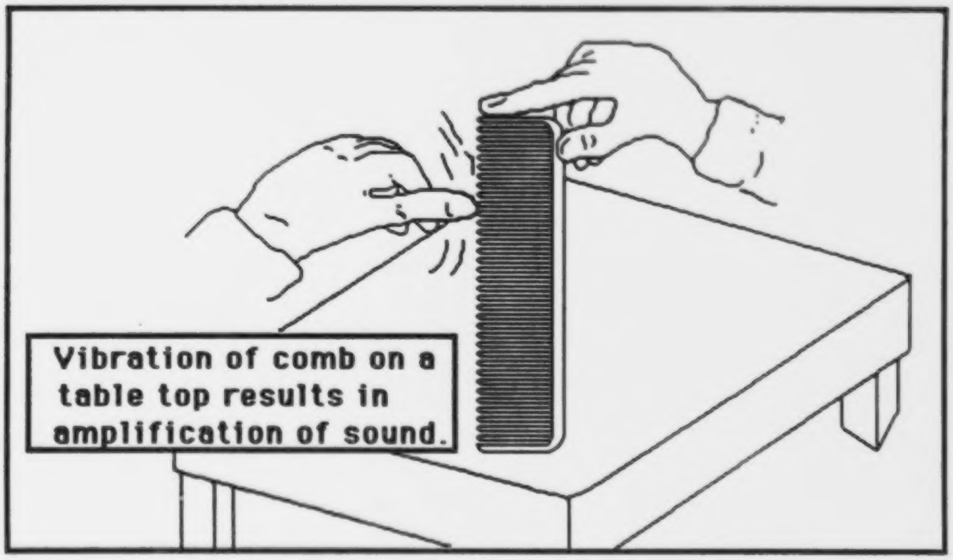
Call on several students to explain their answers.
Give the students enough time to **think of a complete explanation** and to clearly explain it to the class.

Answer -- Skinnier rubber bands have less material or matter than thicker bands. Because there is less material, the thinner band sets up a wave motion that has more waves per unit length. The wave length of the wave produced in the band is shorter in the skinnier band than the thicker band. And the shorter the wave length, the higher the frequency. Also, the higher the frequency, the higher the pitch of the sound produced.

At first, few students will be able to provide such a thorough explanation of a simple event, but if you encourage them and expect them to do so they will improve. Remember, the less you expect of students, the less they will give you, and their thinking will be fragmented and filled with misconceptions.

AMPLIFYING SOUND

Demonstration


Vibration of comb on a table top results in amplification of sound.

PURPOSE

Many people find joy in loud sounds, it seems to do something for them "psychologically". Teenagers in particular like loud sounds. They appear energized from music which is blasting. Therefore, you can get young people's attention with activties that demonstrate the amplification of sound, and reinforce basic concepts of sound and hearing. Doors, table tops, and boxes are but some of the common objects in our everyday environment which can be set into vibration to demonstrate sound amplification.

MATERIALS

- At least one large comb
- An available table top
- An available door
- Musical instruments brought to class by students
- A large and a small metal can
- A large and a small box

PROCEDURE

1. Hold the comb up in the air and run your fingers quickly over the teeth. Ask, who can hear the vibration from the comb? Who can barely hear the comb vibrate?

Give many students an opportunity to respond, especially those that are farthest away from you because they will have difficulty hearing the comb hum.

Reinforce students for their responses--this builds good rapport.

2. Ask, how can we run our finger nail along the comb and produce a sound everyone in this room can hear? Elicit many respones from the students and list them on the chalkboard. Then try out the ideas. Call on different students to verify their suggestions. You can pass out several combs or ask the students to get out their combs and hear how various objects in the room amplify sound.

Note: when you pluck the comb and rest one end on an object it amplifies the sound emanating from the comb, which is very pronounced.

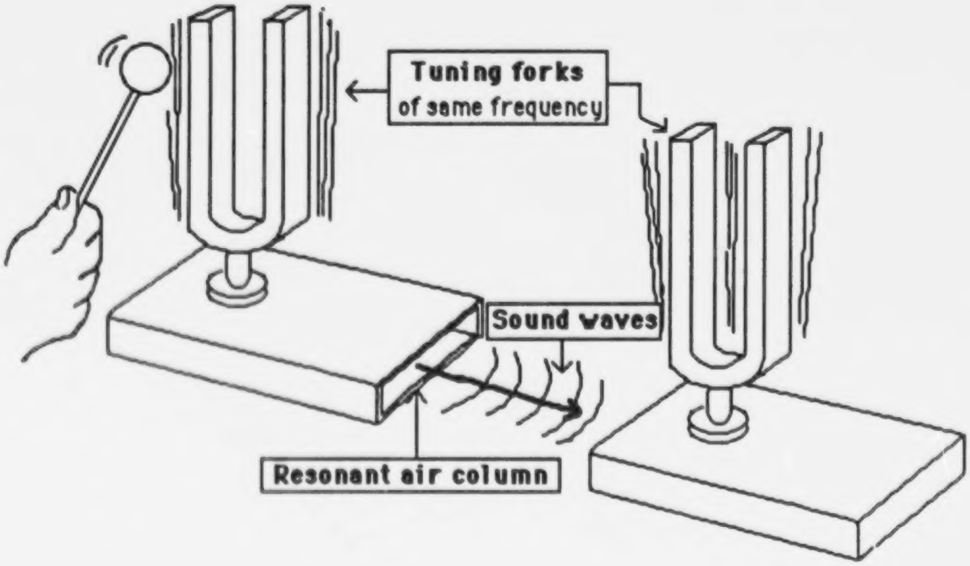
3. Now ask the students to explain why placing the comb on an object causes amplification of the sound. **Wait at least three seconds** after you pose each question before you call a student to respond, and give the students plenty of time to explain. Wait, wait, wait!

Answer -- When the vibrating comb is set on an object, the whole object vibrates. In general, the larger the vibrating object the louder the sound. The top of a table will be louder than the top of a small box. It may be difficult for some to realize that this small comb can set into vibration a large table top or door. Be sure students indicate that the **surface area** of the vibrating object is proportional to the amplification of the sound it emits, all other things being equal: (a) distance from the sound source, (b) the amplitude of the sound source, (c) construction of the amplifier, and (d) composition of the amplifier. Wood is an excellent amplifier of sound, which is why pianos, guitars, and violins are made out of wood.

4. Ask students to bring to class some string instruments to demonstrate sound amplification and vibration. This will increase class participation and emphasize the objective of this demonstration.

SOUND AND MUSIC THROUGH RESONANCE

Demonstration



PURPOSE

Each object produces its own special sound when it is caused to vibrate. This sound is the natural frequency of the object. A fascinating phenomenon occurs if two objects have the same natural frequency because a sound produced by one will cause vibrations in the other. This phenomenon is known as **resonance.** Resonance enhances sound and music. Musical instruments are designed, for example, to increase the original vibrations that are induced by the musician. The long tubes of brass instruments resonate at harmonically related frequencies, which are produced by the vibrations from the pursed lips of the musician. In addition, "physical resonators are used in some musical instrument. The vertical metal tubes under the wooden bars of xylophones and marimbas, the bamboo tubes under brass bars of gamelans, act as resonators that intensify and prolong certain harmonies generated by striking the bars " (Pierce, 1983; p. 46).

This activity will increase students' awareness of resonance, where it occurs and how to produce it.

MATERIALS

Two tuning forks with the same frequency
A wooden mallet
Two sounding boards, or small wooden boxes
A few brass and reed instruments (students who play these instruments can bring them to class)

PROCEDURE

1. Set up only one of the tuning forks as pictured above. If you do not have a sounding board where you can set the handles of the tuning forks, call on a student to hold the fork down against a surface which will amplify the sound.

2. Ask the students to listen carefully as you strike one of the forks. Be sure the students can hear the hum of the fork; tell them to gather around the demonstration table if necessary. Strike the fork a few times, listening each time to determine how loud the humming is.

3. Now place the second tuning fork near the first one. Ask the students to predict what will happen to the sound when you place the second fork near the first and strike the first fork. Probe their responses and ask them to explain. Strike the first tuning fork and observe the resonance. You must practice this beforehand to be sure it works well.

Again, call on students to explain why the sound emanating from the first tuning fork is now enhanced by the presence of the second tuning fork. After several students have had an opportunity to explain this phenomenon, place the word **resonance** on the chalkboard and use it to explain: the vibration that occurs when one object vibrates at its natural frequency due to the vibration of another object.

Ask a few students to strike one or the other fork so that resonance can be observed. Again, **call on several students** to determine if they can define and explain resonance.

4. Ask students who brought to class their reed and brass instruments to get them. Request them to demonstrate the effects of resonance by removing their mouth pieces and blowing through them and by placing the mouth pieces back on the instrument and blowing through them. The differences are striking.

5. Ask students to give examples of resonance in their environments.

Does any one know that air in the ear canal -- the passage from the ear to the eardrum -- resonates? Well, it does.

Does any one know how much the resonance in the ear canal increases pressure of the sound waves which enter this canal?

"For the frequencies between 2,000 and 5,000 vibrations per second, the sound pressure at the eardrum is approximately 10 times the pressure outside the opening of the canal" (Stevens and Warshofsky, 1980; p. 36).

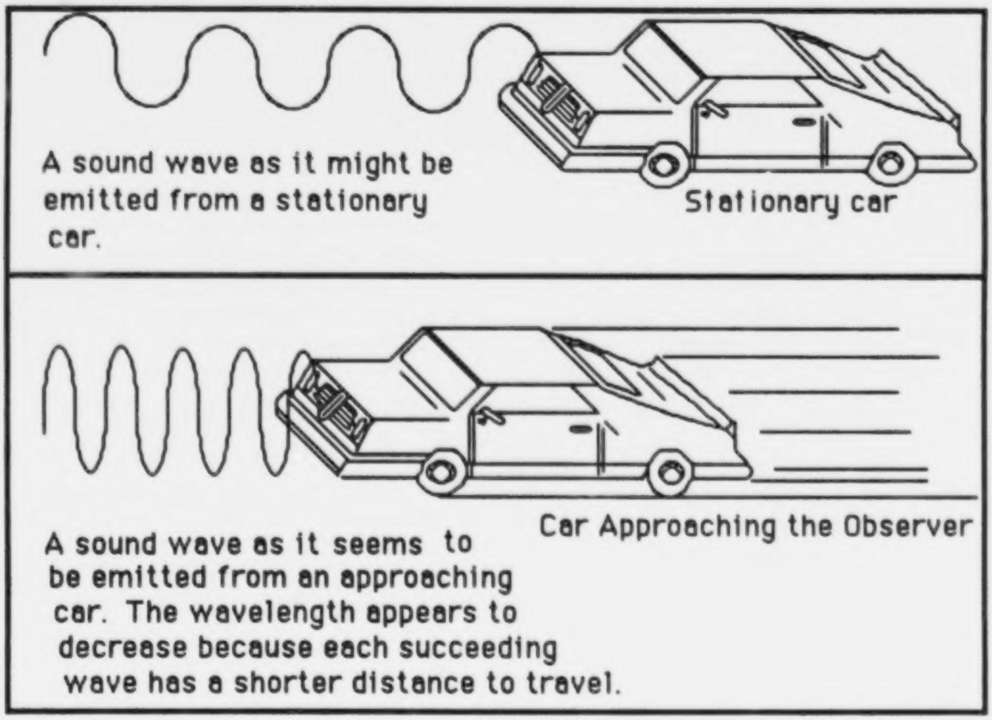
REFERENCES AND SUGGESTED READINGS

Pierce, John R. (1983) The science of musical sound. Scientific American Liabrary, New York.

Stevens, S. S. and Warshofsky, F. (1980). ***Sound and hearing.*** Time-Life Books, Alexandria, Virginia.

THE DOPPLER PRINCIPLE

Demonstration



A sound wave as it might be emitted from a stationary car.

A sound wave as it seems to be emitted from an approaching car. The wavelength appears to decrease because each succeeding wave has a shorter distance to travel.

PURPOSE

In 1842 Johann Doppler, an Austrian physicist, noted that sound coming from a moving object will change pitch as it approaches or moves away from a stationary listener. A train whistle, for example, appears to emit a higher pitch whistle as it speeds toward you, and then appears to emit a lower pitch whistle as it moves away. The actual pitch of the whistle does not change, but the sound you hear does because of the effect a moving object has on sound waves.

Sound waves can be used to illustrate the Doppler principle (often referred to as the Doppler effect), which is the variation of pitch heard when a source of sound and the ear are moving relative to each other. The Doppler principle is used to reinforce the idea that sounds travel as wave disturbances and have a pattern of compressions and rarefactions. Light rays and radio waves also illustrate the Doppler effect.

MATERIALS

Tuning fork with a hole in the handle
A wooden or rubber mallet to strike the tuning fork
Several meters of strong string

It is preferable to use a tuning fork with a high pitch because the variation in sound can be detected easier than with a lower frequency tuning fork. If you do not wish to drill a hole in the handle of a tuning fork, you can purchase a Doppler effect demonstration kit from the science supply companies.

PROCEDURE

Cut a piece of strong string about one and a half meters in length. Securely fasten one end of the string to the hole in the handle of the tuning fork. Grasp the end of the string with one hand. With the other hand, grasp the string about one meter from the tuning fork and twirl the fork around to get the feel of this and to be able to do this without hitting any students.

Then strike the tuning fork with a mallet and twirl it around. It may be difficult for you to hear the change in pitch because the vibrating fork is neither moving toward you or away from you. But a person about two meters away can hear the pitch of the sound change as the fork approaches and moves away during its rotation.

Practice this before you present the demonstration to the students. Get the help of a colleague or a student to listen for changes in the sound emitted from the rotating tuning fork. Determine the optimal distance a person should stand from the swirling tuning fork to hear it vibrate and note the change in its pitch.

Caution: Request observers to **wear safety goggles** to protect their eyes in the event the tuning fork should fly off the string into someone's face.

2. **Demonstration to class.** Assemble the class in a half circle in front of you. Request students to stand two or three deep in a semicircle arrangement, more than two meters from you. With the students in front of you, you can observe them and judge their distance from you as you twirl the tuning fork over head. Do not permit students to stand behind you, for you have little control over their behavior when this situation occurs. If you have a large class, divide it in half and call one half of the class at a time to participate in the demonstration, while the others remain seated.

3. When the class is orderly and quiet, strike the tuning fork with a mallet and twirl it above your head. Repeat this activity until all students can hear the change in pitch of the rotating fork. Then ask the following questions:

- What do you hear coming from the tuning fork as it whizzes by you?
- Can you explain this phenomenon?
- Can you sketch the sound waves that the listener receives?

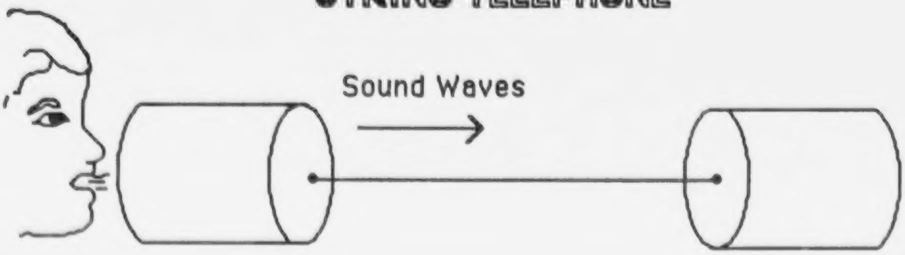
Answers -- Observers should hear the high pitch buzz of the tuning fork go up as it approaches them and go down as it moves away. This occurs because an object moving toward you and emitting sounds, continually sends out sound waves. This rapid fire emission of waves causes the compressions of waves to crowd each other and move closer together. The resulting sound wave system is one that has compressions and rarefactions which are closer together than a sound source that is stationary relative to a listener. This is illustrated in the diagram shown on the preceding page.

The Doppler effect can be observed in everyday life when a siren from a police car or ambulance is heard. Radar guns used by law enforcement officers to detect speeding automobiles use the Doppler principle to calculate their speed. Study the diagrams on the preceding page and observe the sound waves originating from the stationary car versus the moving car. Note how much closer the wave crests are from the moving car.

Place the car diagrams on the chalkboard and ask the students to sketch the sound waves emitted from the cars. Be sure all of the students participate so they can reinforce their knowledge of the Doppler principle and better explain the nature of sound waves.

THE STRING TELEPHONE

Laboratory Exercise
-- for the teacher --



STRING TELEPHONE

As the voice is channeled into the can, the string becomes the medium in which the sound waves travel to the other can.

BACKGROUND

Most people have played with a "string telephone" in their youth. It consists of two cans connected by a line. This device can be constructed to effectively transmit our voice. It is ideal for investigating the production and transmission of sound. Nevertheless, few people have studied this simple device to demonstrate the nature and transmission of sound.

The "string telephone" can be developed into a science process laboratory activity which permits students to identify the variables that contribute to the quality of voice transmission. For example, how does the composition of the phones contribute to the quality of the voice that is heard in the system? How does the size of the phones affect the clarity of voice transmission? Or how does the composition of the line make a difference in the loudness and the clarity of the sound?

Certainly the **flexibility** of the materials used in the construction of the "string telephone" affects its quality. Flexibility is a factor that relates to sound transmission and will be discussed with students.

The purpose of this laboratory is to encourage students to determine which variables contribute to the quality of sound in a "string telephone." In other words, what materials should one use to construct a "string telephone" that transmits the clearest voice messages?

PRELABORATORY DISCUSSION

Before you present this question, construct a set of phones and ask some students to use them in the classroom or laboratory room.

You might use two plastic cups connected by a thread which is almost the length of the room.

Encourage several students to talk over the phones and listen to their voices.

Then ask the class, "What materials would you use to make a string telephone that transmits the **clearest** voice?" (Write the question on the chalkboard.)

As the students suggest the variables or factors, list them on the board. For example:

Composition of phones--metal, paper, plastic

Size of phones--small, medium, and large

Composition of line--thread, plastic, metal

After the students have listed many variables, form groups and ask each group to select a variable they wish to investigate.

Ask each group to **predict** which variable change they believe will produce the best improvement in the sound. The students should record this on their lab sheet and you should note these predictions on the chalkboard.

Here are some set-ups to consider:

- Three types of phones, all with approximately the same diameter (you do not want to introduce another variable to confound this test). Paper cups, plastic cups, and metal cans (10 ounce).
- Three sizes of phones, all made of the same material. Six ounce tomato paste cans, one pound coffee cans, and two pound coffee cans work well.
- Three types of lines, all of the same diameter. Plastic fishing line, cotton quilting thread, and wire.

PURPOSE

To determine which factors or variables contribute most to the quality of voice transmission over the "string telephone."

MATTERIALS

4 (6 oz.) tomato paste cans 4 (16 oz. or 1lb.) coffee cans 4 (32 oz. or 2 lb.) coffee cans	2 spools of strong cotton thread	(PHONE SIZE)
4 (8 oz.) paper cups 4 (8 oz.) plastic cups 4 (8 to10 oz.) metal cans	2 spools of strong cotton thread	(PHONE COMPOSITION)
12 (12 to16 oz. or large) plastic cups	2 spools of strong cotton thread 2 spools of 28 gauge galvanized single strand wire 2 spools of 8 lb. test monofilament fishing line	(LINE COMPOSITION)

These quantities will accommodate two groups of students in which each group is examining the same variable. For example, consider the "size of phone" investigation using the tomato paste and coffee cans. Each group will need two tomato paste cans, two 16 oz. coffee cans, and two 32 oz. coffee cans, which totals to 12 cans indicated above.

You will have to plan ahead of time to collect the cans. One pound coffee cans are common in most households. Two pound coffee cans might be obtained from the cafeteria or a neighbor who drinks a great deal of coffee. Remember, students are a great source for these materials: just ask and they will supply most of them.

Paper and plastic cups, and metal or "tin" cans are readily available in the grocery store. Plastic cups can be bought by the package; yogurt containers are great. Check the soup section for cans that are approximately 10 ounces in size. Many cans are 15 ounces.

The wire can be bought at the hardware store or at Sears. It should be the same diameter as the thread and fishing line (28 gauge wire is about the right size).

Quilting, button, or carpet thread is ideal for this activity and can be obtained from a cloth or department store. Red or colored thread works well because it can be seen easily. Heavy cotton thread seems to transmit sound better than anything we have tried.

Plastic fishing line can be obtained where sports equipment is sold; we have found that it does not transmit sound very well. Eight pound test monofilament line seems to be the same diameter as the thread and wire described above. All of the lines should be the same diameter so as not to introduce another variable which will confound this experiment.

Making holes in the bases of the phones is an easy matter. Use a common pin and push it through the base from the outside inward. With the metal cans and plastic cups, use a hammer to tap on the head of the common pin to pierce the base of the phone. Thread the line through the hole in the base of the phone and tie a large knot at the end to keep it from coming through. Some people tie the line to a toothpick to secure it, especially with the paper cups.

PROCEDURE

1. After the prelaboratory discussion and the formation of student groups, assign each group to study one variable that affects sound transmission. Carefully select an area to conduct these activities because they will be noisy. Some teachers remain in the lab room, while others move the class to a remote place in the school or outdoors. If there are many classrooms adjoining a hall that you are considering to use, this activity may be too noisy for those in these classrooms--even with the door closed. These exercises generate a great deal of excitement, movement, and talking.
2. Ask one student from each group to get the necessary materials for his/her group to investigate the variable under study. You may have two or three groups studying the same variable if you have a large class. This is fine because it permits you to compare and challenge results and procedures, especially how groups determined the clarity of voice transmission.
3. You need to monitor these activities carefully so that students stay on task and proceed at a reasonable rate. Consider the following precautions:

    - Make all of the lines connecting the phones the same length.
    - Phones should be held so they are parallel to the floor and line connecting them.
    - Make sure the students keep the lines tight, but not to the point of pulling them through the phones.
    - Ask students not to hold their phone and the line at the same time when they speak: the line should not be touched.
    - Keep the groups separated so they do not get their lines tangled.

4. When the groups have completed their work, assemble them for the postlaboratory discussion.

POSTLABORATORY DISCUSSION

The postlaboratory discussion is an opportunity to promote an understanding of sound transmission. Density and flexibility are two major ideas that should be emphasized during this discussion.

1. On the chalkboard, write the variables each group of students investigated (if this is not already on the board), and indicate the variable(s) that was hypothesized during the prelaboratory discussion to be best transmitter of voice messages.
2. Ask a spokesperson from each group to report the findings and to explain them.

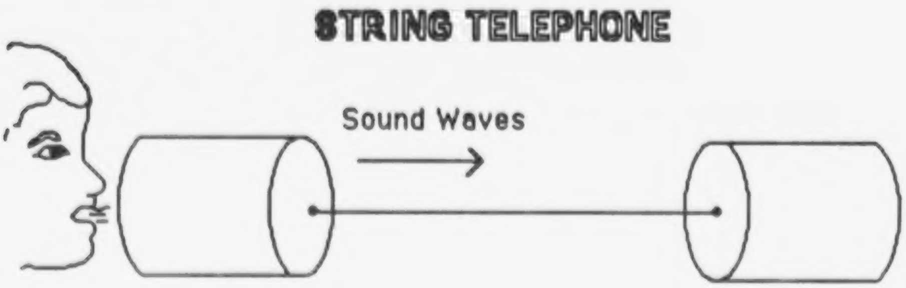
    - Call on many students to explain why some materials work better than others.
    - Give each person plenty of time to answer--wait, wait, wait.
    - Ask students for evidence to support their results and assertions.
    - Reinforce students for their responses.

3. If you have two or more groups investigating the same variable (e.g. size of phones), you may find disagreement. In these instances, discuss the discrepancies and urge them to try out the procedures again. Involve students in other groups to determine which variable produces a given outcome, and let them defend their responses. When scientists and engineers encounter a discrepancy, they attempt to resolve it by retesting.
4. Now pull this investigation on the "string telephone" back together. Take the specific variables that were identified by the class to produce the best voice transmission and construct a set of phones with these characteristics. Depending on the materials used, different classes may arrive at different sets of variables which they believe produce the best "string telephone".

Which worked best in this laboratory? Did the paper phones connected by the thread work best, which is often the case, but not always? Or did the large plastic phones connected by the wire work best, which is unlikely, but may have occurred with the materials you used?

5. As an assignment, ask your students to write a paragraph describing the components of a "string telephone" and what part they take in the transmission of sound.
6. Another assignment could be to ask students to build some phones at home and bring them to class for a competition to determine who can make a telephone that works best.

THE STRING TELEPHONE
Laboratory Exercise
--for the student--



PURPOSE

Determine which variables contribute to the quality of speech transmitted with a "string telephone".

MATERIALS

4 (6 oz.) tomato paste cans	2 spools of strong cotton thread
4 (16 oz. or 1 lb.) coffee cans	
4 (32 oz. or 2 lb.) coffee cans	
4 (8 oz.) paper cups	2 spools of strong cotton thread
4 (8 oz.) plastic cups	
4 (10 oz.) metal cans	
12 (12 to16 oz. or large) plastic cups	2 spools of strong cotton thread
	2 spools of 28 ga. single strand wire
	2 spools of 8 lb. test monofilament fishing line

PROCEDURE

1. Your teacher will assign you to work with a group of students to study the effects of one variable on how well voice is transmitted over a "string telephone". The variable that your group has been assigned might be what the phones are made of (composition of phones), or it might be what the line is made of (composition of line), or the size of the phones. Whatever the variable is, write it on the line below and keep it in mind as you conduct this experiment.

Variable under investigation: ______________________________

2. Follow these suggestions when conducting this exercise:

- Make sure the lines connecting the phones are the same length.
- Keep the phones straight (parallel to the line attaching the phones) when you speak.

- Keep the line tight when you speak or listen, but not so tight that you pull the line through the hole where it is attached.
- Do not touch the line or the base of the phones when you speak or listen.
- Speak up when you speak into these phones--it takes a certain amount of voice-power to send a sound over the line with these mechanical devices.

3. Each person in your group should listen and speak over the line. However, when everyone has had an opportunity to do this, select one person to speak and one to listen. Use these people to test out the variable your group is studying. The speaker should speak with the same loudness each time: this is the only way you can accurately test your variables. When the two "testers" think they have found the variable which transmits voice messages the clearest, ask other members of the group to listen and see if they agree.

CONCLUSIONS

1. Write down the variable that your group was assigned to investigate:

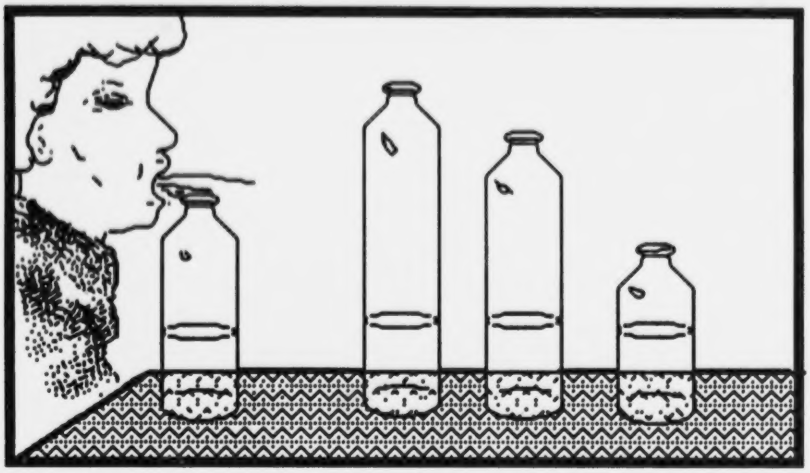
2. Write down the aspect of the variable that your group found best transmits voice messages over the "string telephone".

3. How accurate did you (or your group) predict?

4. Explain why, when you change your variable, sound is transmitted better.

5. After your class has had a postlaboratory discussion on this lab exercise, name all of the variables that you would use to make the best "string telephone".

PLAY ME A TUNE
Laboratory Exercise
--for the teacher--



PURPOSE

The highpoint in a unit on the study of sound is when you give students the opportunity to use their knowledge of this topic to make music. Constructing a crude musical instrument and actually playing a favorite song will be an experience students will never forget and one which will increase their appreciation for science. This **exploratory** laboratory exercise will help students expand their concept of **pitch** and **timbre,** encouraging them to use their creative talents to construct musical instruments that will produce notes of different pitches and the music of a simple tune.

MATERIALS

Several bottles of various sizes--pop bottles work well
Several feet of flexible vinyl tubing (tygon): 1/2" or 3/4" in diameter
Several feet of plastic plumbing pipe (PVC pipe): 1/2" or 3/4" in diameter
Cotton balls
A pitch instrument
Sheet music

You must **begin preparation** of this hands-on experience many weeks before it takes place. Find out where to get the materials so that you can direct students to stores where they can buy them. Also, with the materials on hand, you can construct some of the homemade instruments and have a better understanding of how to help students with this task.

Vinyl tubing can be bought at hardware, plumbing or auto parts stores. It is easy to cut into sections of different lengths to produce sounds of different pitch. Plastic plumbing pipe can also be cut to different lengths with a hacksaw to produce different tones. It can be bought in hardware and plumbing stores as well as at the lumber yard. The cotton balls are used to plug the bottom of the vinyl and plastic pipe so that when you blow over them you produce a tone. Note that some students will choose to use vinyl tubing while others will choose plastic pipe to construct their musical instruments, and still others will choose bottles.

It is always nice to have plenty of bottles on hand for this activity, which you can keep from year to year. In schools in low income areas, you may have to provide materials for most of the students and a classroom set of bottles or tubes may be necessary to have in the storeroom.

The cotton balls are used to change the pitch of the sound produced by the wind instruments. Cut a tube approximately five inches long. Wet a cotton ball and stuff it into the bottom of the tube (or pipe). Now blow over the top of the tube. Push the cotton ball further into the tube and blow over it--the pitch changes. In order to change the pitch of the sound produced from the bottle, change the level of the water in the bottle.

We must advise you that some students experience great difficulty producing a tone by blowing over a bottle or tube; this requires more skill than you might imagine. See the prelaboratory discussion for more on this subject.

Consult with the music teacher in your school or go directly to a music store to get a pitch instrument. A pitch instrument or a piano is necessary to produce different tones so that the instruments can be constructed and tuned to produce specific notes. The music you select should be very simple and comprised of as few different notes as possible. Some songs have only five or six different notes, which makes it easy to construct a wind instrument to play these notes. For example, John Denver sings a song called "Annie's Song" that has six different notes which are close together in pitch. Familiar nursery rhymes work well such as "Three Blind Mice" and "Row Row Row Your Boat". There are many simple tunes that have relatively few notes in their composition. Be sure to get sheet music with the words, this makes it easier to appreciate and hum. Remember, of course, to ask students in your classes for ideas; some of them play instruments and are good musicians.

PRELABORATORY DISCUSSION

Discuss with students the purpose for this activity and try to make this an "upbeat experience". Demonstrate one of the homemade instruments by playing a song. Then show the construction of your instrument and how it produces notes of different pitch. This would be a good opportunity to mention the variables that relate to the production of high and low pitch tones such as the effect of increasing the length of the column of air in a pipe or tube, or what happens to the pitch when you tighten a string.

Spend plenty of time demonstrating how to produce a tone by blowing over the lip of a bottle or a tube. You will discover that it requires one to blow somewhere between two extreme positions: across the top of the lip and directly down into the bottle. Call on certain students to try this and to follow your directions.

Although the materials above specify those for wind instruments, there is no reason that students cannot construct string instruments. However, string instruments that produce certain tones are more difficult to make and tune than wind instruments.

Some teachers prefer to let students select their own music. Others select one piece of music or song for everyone to play.

After you have "turned students on" to this activity, give them a date to complete their instruments and the criteria for successful completion of the assignment. Since you made an instrument you should have some idea how long this will take students to complete their work. As for lab credit, we suggest developing criteria and points that **encourage exploration and interest in science**; don't kill this activity by the threat of losing points on a lab grade. The following are some criteria you might consider to evaluate a student-made instrument:

- Produces several tones
- Produces several tones that accurately correspond to specific musical notes.
- Student attempts to play a song on it with little success.
- Plays a song on it with modest success.
- Plays a song on it with great success--it sounds good and you can recognize the song.

There are many other criteria that you can think of to achieve the end results that are appropriate for a given class.

PROCEDURE

1. One way to get this activity off the ground is to spend a lab period helping students put their wind instruments together and tuning them to certain notes on the musical scale. Many students need this structure. In addition many students do not have access to a piano or a pitch instrument

and will need your help and the use of your pitch instrument. When you conduct this session, be sure students bring materials and sheet music. You might have some extra vinyl tubing or plastic pipe on hand for students who come to lab without these materials.

You must carefully organize this activity because noise can be a problem. If many students are producing sounds, accompanied with some talk and laughter, it may be difficult for individuals to hear what they are playing.

2. Designate a laboratory period when everyone will demonstrate his or her musical instrument. Call on individual students to play notes of different pitch and to play music; this will permit you to evaluate individual products, if it is appropriate.

3. If the entire class is using the same song, you can ask those who are prepared to play this piece of music all together. Should we contact RCA Recording Company for an appointment to cut a record for your class?

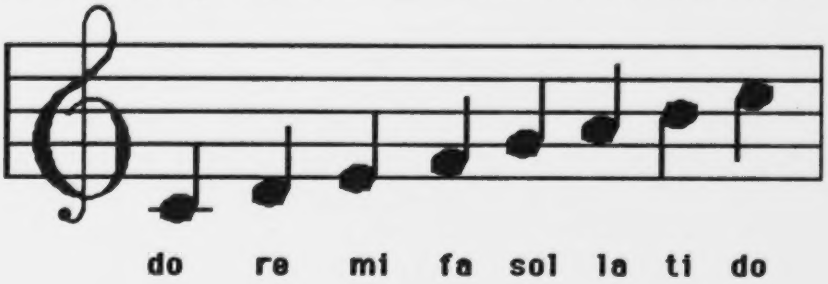
POSTLABORATORY DISCUSSION

This is a great opportunity to reinforce concepts related to sound. Be sure to call on many students to respond, especially those who were not successful in constructing an instrument that produced good notes or music.

What is pitch? Wait at least five seconds before you call on a specific student to answer this question. Also, call on several students until you get responses similar to the one below.

Answer -- Pitch is how high or low a tone sounds, and it is related to the frequency of the fundamental sound wave that strikes your ear.

Call on students to produce certain tones with their wind instruments. Associate these notes with the musical scale, calling students to the chalkboard to indicate the notes that are played.



Call attention to the wind instruments that produce the highest and lowest notes. Ask students to come to the chalkboard and explain why a particular instrument produces a given tune. Call on several students, allowing each to build on the answers of others until the the explanation is complete. Remember, the longer the air column, the longer the wavelength of the sound wave vibrating in an air space. And the longer the wavelength, the lower the frequency and the lower the pitch.

What is timbre?

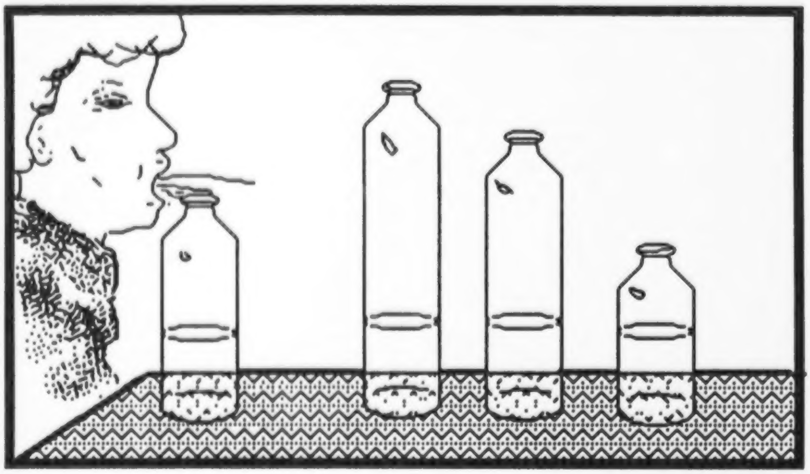
Answer -- Timbre is the characteristic of a tone that associates a sound with a certain instrument. Timbre is the result of harmonics produced by a vibrating object. Since each object or instrument produces a unique set of harmonics along with each fundamental note, we can distinguish the "A" note produced by a harp from the "A" note produced by a trumpet.

This is an opportune time to call on students to demonstrate timbre by playing identical notes on two different instruments. Ask students who play instruments in the band or orchestra to bring their instruments to class and to produce sounds characteristic of a given instrument.

PLAY ME A TUNE

Laboratory Exercise

--for the student--



PURPOSE

Construct a musical instrument that will produce certain notes. With this instrument, play a simple tune or familiar song. We recommend building a wind instrument for this activity because it will be easier to accomplish than a string instrument. Also, you should have little difficulty getting the materials for this homemade instrument.

MATERIALS

Select one of the following type of materials to construct a wind instrument:

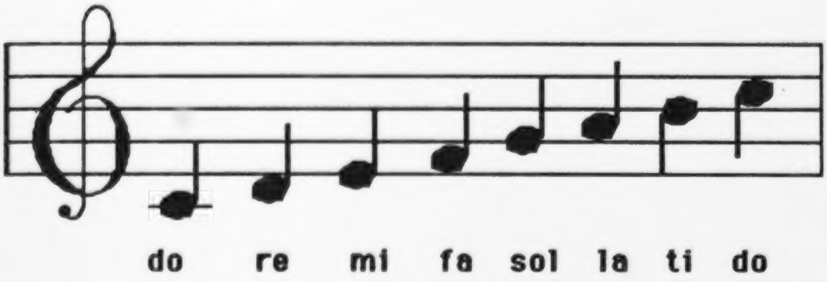
- a. Bottles of various sizes, or
- b. Vinyl tubing (1/2" or 3/4"), or
- c. Plastic plumbing pipe (PVC pipe, 1/2" or 3/4").

Approximately ten cotton balls

A pitch instrument

Sheet music

Before you collect all of your materials, try some of the objects suggested above to determine if you can produce a sound with any one of them. Select an object that you can produce a clear tone with.



Identify a piece of music that does not have too many different notes. Find one with less than 10 different notes. You must construct a wind instrument that can play all of the notes on the song. Familiar nursery rhymes such as "Three Blind Mice" or "Row Row Row Your Boat" are fine for this purpose, or a simple ballad is fine. Ask a music teacher, a musician, or a clerk in a music store for suggestions.

PROCEDURE

Your teacher will outline and coordinate this laboratory exercise, but the following is what you can plan for during this experience.

1. Identify what type of material you will use to make a set of wind instruments that will play many different notes--each with a specific pitch.
2. Find a song or piece of music that you can play with your wind instruments. Remember, you must be able to play all of the notes from the song you select.
3. The following are criteria for different levels of performance with your instruments:
   - Produce several tones.
   - Produce several tones that accurately correspond to specific musical notes.
   - Attempt to play a song, but with little success.
   - Play a song with moderate success.
   - Play a song with great success--it sounds good to others and they easily recognize the song.

CONCLUSION

1. How much did you enjoy this experience?
2. How much did you learn about sound and especially pitch from this laboratory exercise?
3. Define and explain pitch:
4. Define and explain timbre:
5. What suggestions would you give to your teacher when he/she attempts to conduct this activity again?

APPENDIX A: Questionnaire for Assessment of a Science Course (QASC)

QUESTIONNAIRE FOR ASSESSMENT OF A SCIENCE COURSE
(QASC)

Name of Science Course________________________________

The Number Grade You Received in This Course for the
Last Grading Period______

School__________________________

Your Grade Level________ Date___________

INSTRUCTIONS: Please indicate how you **feel** about this science course. Read each statement carefully. Circle the letter that best indicates your feeling about each statement. Below are the responses you can make:

KEY: N = never, S = sometimes, O = often, A = always

The following is a sample item, please read it.

The information in this science unit is **useful** to my life........ N..(S)..O...A

Since S was circled, it means the information was believed to be useful to the person's life--**sometimes.**

A. HOW MUCH DO YOU ENJOY THIS SCIENCE COURSE?

1. Science class is often boring.. N...S...O...A
2. Science class is usually fun.. N...S...O...A
3. I enjoyed going to science class.. N...S...O...A
4. I am afraid to ask questions.. N...S...O...A

B. HOW USEFUL IS THE INFORMATION TAUGHT IN THIS COURSE?

5. The information is useful to me... N...S...O...A
6. The information is meaningful to my life............................... N...S...O...A
7. This information should be required in science classes... N...S...O...A
8. I will be able to use the information in the future............. N...S...O...A

Key: N = never, S = sometimes, O = often, A = always

C. HOW DID YOU FEEL IN SCIENCE CLASS DURING THIS COURSE?

9. I felt uncomfortable during this course .... N...S...O...A
10. I was curious .... N...S...O...A
11. The classes made me feel stupid .... N...S...O...A
12. I felt confident .... N...S...O...A
13. The class made me feel successful .... N...S...O...A
14. I was unhappy in class because of this course .... N...S...O...A

D. WHAT TOOK PLACE IN THE CLASSROOM DURING THIS COURSE?

15. Our teacher asked many questions .... N...S...O...A
16. We were expected to explain events or ideas .... N...S...O...A
17. We were given plenty of time to think about answers to our teacher's questions .... N...S...O...A
18. Our teacher's questions really made us think .... N...S...O...A
19. We were given enough time to answer questions .... N...S...O...A
20. The questions really made us learn about the demonstrations and laboratory work .... N...S...O...A
21. We were given many paper and pencil exercises to help us learn this unit .... N...S...O...A

E. OVERALL RESPONSE TO THIS COURSE?

22. I enjoyed this course .... N...S...O...A
23. I learned a lot during this course .... N...S...O...A

F. **Please write several comments** about your impression of this science course--what you liked or disliked about it.

1. ____

____

2. ____

____

3. ____

____